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KALLIOPE

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ONTOLOGY-BASED RESTRUCTURING OF KNOWLEDGE TO SUPPORT IDEA GENERATION

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ABSTRACT

Over the years, the ability to generate ideas to solve problems has become more important in economy and science. The goal of this masters thesis is to develop a structured, knowledge-based approach to support people in generating ideas in the context of innovative design tasks.

An approach is developed that aims at restructuring knowledge of a problem domain by means of synthesizing questions and suggestions that are related to the problem domain. This knowledge, as well as knowledge from several other domains, is semantically structured and stored in an ontology. Using this ontology and applying generic strategies for restructuring knowledge, sentences are synthesized that can inspire the user to generate ideas that might prove useful in the context of the problem at hand.

Furthermore, a new method to evaluate ideas is developed. As an additional, objective quality criterion for evaluating ideas I propose `variety`. The variety is a measure for the difference of ideas regarding their characteristics; it is calculated using the Hamming distance.

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CONTENTS

ACRONYMS

AI	Artificial Intelligence
DB	Database
FHD	Fact Hamming Distance
HD	Hamming Distance
IGS	Idea Generation Session
KB	Knowledge Base
SHD	Signature Hamming Distance
SQL	Structured Query Language

SYMBOLS

a	an `attribute`
A	the set of `attributes`
c	a `concept`
C	the set of `concepts`
v	a `value`
V	the set of `values`
$\phi(c)$	the corresponding function of the `signature` of a concept c
$\psi(a)$	the corresponding function of the `domain` of the attribute a
$\rho(a)$	the corresponding function of the `range` of an attribute a
$\theta(c, a)$	the corresponding function of the `fact` relation of a concept c regarding an attribute a
$\omega(v, a)$	the corresponding function of the `opposite_of` relation of a value regarding an attribute a
$\mu(v)$	the corresponding function of the `value_is_concept` relation of a value v
$\sigma(c)$	the corresponding function of the `specialization_of` relation of a concept c
$\chi(c)$	the corresponding function of the `abstraction_of` relation of a concept c
$\alpha(c, \delta)$	the corresponding function of the `akin_to` relation of a concept c regarding a specific degree of kinship
$\zeta(c, \delta)$	the corresponding function of the `similar_to` relation of a concept c regarding a specific HD
$\wp S$	the power set of the set S

1 INTRODUCTION

In ancient times, from antique Greece until the Middle Ages, creativity was not seen as an ability of the individual, but a gift or a divine insight. In Greek mythology, the muses were thought responsible for any inspiration that lead to creativity. The muses are the daughters of Zeus, king of the gods and Mnemosyne, goddess of memory. Kalliope, the oldest and wisest of them, was the muse of epic poetry and science, and is now best known as Homer's muse, the inspiration for 'The Iliad' and 'The Odyssey' [10]. Inspiration could have happened to everybody, but only the artist could make use of it, because of other talents, techniques and skills. This belief changes slowly with nascent psychology in the 18th century. From then on, inspiration was regarded as an ability located withing the personal mind, but still seen as a gift, a God-given talent like genius, and also associated with madness and irrationality[8]. Until today the phenomenon creativity is controversial and the term inspiration is nearly never touched in science or technology.

In this thesis an algorithmic approach is developed that intends to inspire people by means of inspirational questions, to support generating more innovative ideas, and also to increase the variety of their ideas. People shall not wait for a kiss of a mystic muse to get an innovative idea. I propose to restructure knowledge that people already have. I think that this is the key to innovative ideas. I assume that the human mind is used to focus, simplify, and make a lot of assumptions of the world. This is a useful mechanism, established during evolution of mankind and exercised in education. But to generate innovative ideas, this mechanism often limits people to solve problems creatively and get innovative ideas. The use of a software framework that intends to scrutinize and challenge the users assumptions and knowledge about the problem might help people to get creative ideas.

1.1 MOTIVATION

Creativity and the ability to generate ideas have become more and more important for economy and science. Innovative ideas are necessary for developing new products and services, for making inventions and creating new technologies. However, to be creative and to find innovative solutions for complex problems is not a trivial process for most people. There are a lot of professionals of several domains who have to generate ideas reliably and repeatable. Several approaches have been developed to support those people.

Psychological approaches have been developed that investigate on creative people, causes and models of creativity. Mainly, these psychological approaches aim at understanding and explaining the phenomenon creativity and the processes of idea generation. Other approaches have a more pragmatic point of view, they aim at supporting people to generate ideas by means of various, often heuristic techniques. These approaches are called 'creativity techniques' or 'pragmatic approaches to creativity', because their basis is often unclear and they do not conform to modern scientific methods. Nevertheless, these 'pragmatic approaches' have been successful with making the topics creativity and idea generation popular in society. And they have changed the common attitude, so that not all kinds of creativity are taken as a gift and a matter of talent any longer.

Beside these pragmatic approaches, there are also some advanced approaches that intend to make processes of idea generation and innovative design more reliable, repeatable, and justifiable. These approaches bridge the gap between pragmatic support to idea generation and investigations of basics and processes of idea generation.

Also, a very popular method to support generating ideas to solve a problem is to analyze and scrutinize this problem. For instance, by means of an interviewer who asks sometimes 'naive' questions and makes 'weird' suggestions to a problem owner (the person who has the problem). Such questions and suggestions often help the problem owner to get a new view on the problem and to find an unusual, unorthodox (innovative) solution. It might be helpful for supporting idea generation processes to synthesize such questions and suggestions that challenge a problem.

Idea generation for innovative design tasks usually happens in terms of a moderated idea generation session (IGS). A moderator applies some supporting techniques to inspire the participants of the IGS to generate ideas and prevents extended discussions. The moderator is required to be a communicative and creative, because he has to inspire the participants to think outside of too traditional and too conditioned thinking patterns. A framework that supports a moderator to inspire people to generate more unusual and unorthodox ideas might be helpful to improve professional idea generation for innovative design tasks.

1.2 SCIENTIFIC HYPOTHESIS

These motivations have lead to the following scientific hypothesis:
It is possible to have an algorithm that supports people, when engaged in processes of innovative design, to generate more innovative ideas.

This hypothesis is clarified as follows:

POSSIBLE TO HAVE : I intend to build an algorithm; to embed this in a software system, and next deploy this in a (staged) IGS.

ALGORITHM : in general, an algorithm is a prescription of a mechanical process that takes place without a need for interpretation. In this case, part of the process will be a computer program; other parts of the process are executed by, respectively, moderators and participants in multiple IGSs[1].

SUPPORT : I do not intend to build a system that produces ideas for solving the task; rather I propose to create an algorithm that

1 I propose a setup where incremental accumulation of knowledge between one IGS and a next is possible. This means that IGSs can build on earlier ones.

aims at stimulating the thinking processes of people, who have to generate ideas in an IGS.

PEOPLE : participants of an IGS, which can be stakeholders of the innovative design task, in example professionals in design, implementation or customers, but perhaps also people with other domain knowledge or expertise.

STAKEHOLDER : all people that are affected by any consequence of the proposed idea made in the design process, in example users, customers, sponsors, and maybe also technicians and designers of the design process[26].

ENGAGE : all people that are participants of an IGS, some are stakeholders of the innovative design task, others are people of some other profession.

PROCESS OF INNOVATIVE DESIGN : also called 'process of creative problem solving' with the requirement for new and appropriate solutions. This process starts with a task to create some innovative product, either material or immaterial. Second, several different ideas have to be generated. The ideas that seem to be most promising in light of the current innovative design task have to be chosen for further processing.

MORE INNOVATIVE IDEAS : generate more ideas (quantitative), that are unusual (quality) when compared to existing or trivial solutions.

IDEA : a new thought of a person. An idea is not necessarily a solution for the design task, but it can lead to a solution for the problem. An idea can be unrealistic or inappropriate. If the idea is promising to lead to applicable solution in the end, it should be processed.

INNOVATIVE : also called `creative`. Something is innovative or creative, if it is both, novel and appropriate, with respect to a purpose.

VARIETY OF IDEAS : the difference of ideas regarding characteristics.

INSPIRATION : an event that initializes the process of having a person producing innovative ideas. Any material object that can be perceived or immaterial object that can be thought of, is a potential source of inspiration. Whether it actually inspires somebody, depends on the person's attitude and abilities.

DESIGN : the verb design is used in a very broad sense for every problem that hinges on making justifiable and conscious decisions for the future benefit of one or more identified stakeholders [47]. So the design of an object, either material or immaterial, is the set of justifiably taken decisions for the benefit of a future situation involving this object.

1.3 TASK

The task of this thesis is to develop a methodology to synthesize sentences that inspire people to generate more unorthodox ideas. This means to perform the following tasks:

- Develop a methodology to synthesize sentences that aim at scrutinizing and restructuring a user's knowledge in relation to a given problem.
- Develop a prototypical implementation of this methodology.
- Evaluate the ideas, generated in the IGSs using this prototype.

1.4 ORGANIZATION OF THIS THESIS

First, a brief overview of earlier work will be presented in chapter 2. Significant approaches to creativity and supporting idea generation will be presented. At the end of chapter 2 the current state of knowledge will be summarized.

The approach for supporting idea generation by scrutinizing and challenging knowledge is introduced in chapter 3. First, an introspection to the approach will be given to elucidate the intention to develop a methodology for supporting idea generation by means of inspirational sentences. Also, the sentences will be specified and analyzed that seem to be inspirational. A grammatic-based attempt to synthesize such inspirational sentences will be presented and discussed. This first attempt gave rise to develop a knowledge-based approach, which will be introduced at the end of the chapter.

This knowledge-based approach using an ontology will be explained in detail in chapter 4. The ontology structure will be defined formally and informally. Furthermore, it will be explained how the ontology can be build up and how it can be used to synthesize inspirational sentences.

A prototype is implemented and tested. This prototype will be presented in chapter 5. The evaluation of this prototype is explained in chapter 6. Also in chapter 6, `variety` as a novel criteria for evaluation will be explained. The last of this thesis, chapter 7, contains a summary and a conclusion of the ontology-based approach for restructuring knowledge. There ideas for improvements and future work will be suggested.

2 PRELIMINARIES AND EARLIER WORK

> The problem of creativity is beset with mysticism, confused definitions, value judgments, psychoanalytic admonitions, and the crushing weight of philosophical speculation dating from ancient times.
>
> *(Albert Rothenberg)*

In this chapter, earlier work on creativity, supporting idea generation and creative problem solving is summarized. First, the psychological and the pragmatic view to creativity and supporting idea generation are introduced. After this, significant examples of earlier approaches of supporting idea generation are presented. Finally, the current state of knowledge based on these examples is summarized.

2.1 CONTEXT AND MOTIVATION

The phenomenon 'creativity' is commonly assessed as important to society. In the context of one's private life, creativity is important for solving problems on the job or daily life or at a societal level for scientific findings, movements in art, new inventions and technical progress, and also for economy [31].

The first domain that put attention on the phenomenon of creativity was psychology. Psychology in general aims at defining the phenomenon `creativity` and investigating causes and circumstances where creativity occurs, and at developing models of the processes that happen in a creative mind.

Also economy discovered creativity as important for creating new products and services that promise competitive advances in the market. The value of creative people was discovered. Some professionals that have to create new ideas professionally developed methods for supporting creativity. These methods are based on their experience, observation, and introspection.

2.1.1 *Psychological View to Creativity and Insights*

The goal of psychological research of creativity is to define and understand the phenomenon. Several definitions and models have been developed that base on introspective, observation, and various experiments.

The official beginning of psychological research on creativity is asserted to J.P. Guilford at the American Psychological Association in 1950. Some early investigations and theories regarding creativity and creative problem solving can be found in the beginning of the 20th century, for instance, in psychoanalysis, associationism, behaviorism and Gestalt psychology [31]. A lot of different definitions of creativity were developed. Until today, psychologists do not agree on one version.

Some people hold the opinion that creativity is something that just does not lend itself to scientific study, because it is a spiritual process. These opinions have made it harder for scientists to study the phenomenon creativity using methods of science [31].

Definitions of Creativity

There are two major views to creativity: 'big C' Creativity and 'small c' creativity. 'Big C' Creativity describes the creativity of the genius and famous. Only solutions to extremely difficult problems, or significant works of genius, are recognized as creative [32]. A common definition of 'big-C' Creativity is given by Robert J. Sternberg: "Creativity is the ability to produce work that is both novel (that is, original, unexpected) and appropriate (that is, useful, adaptive concerning task constraints)"[31]. On the other hand, 'small-c' creativity is used for the 'normal' and 'ordinary' creativity, it does not require anything socially valuable [32]. 'Big-C' Creativity is more often object of psychological research [32]. The definition of 'novelty and appropriateness' is criticized too. In particular, the predicate 'appropriateness' is criticized, because it is defined by a society at a given historical moment [32]. By some strict definitions of creativity only eminent people can be said to be creative.

Myths of Creativity

There are several 'myths' of creativity that exist until today [32]. Myths like 'creativity comes from the unconscious', 'creativity represents the inner spirit of the individual', 'creativity is spontaneously inspiration' where said to originate in romanticism[1]. The myth 'everyone is creative' has its origin in American ideology of democracy. It is based on the deep belief everyone is equal, and that no one should judge what counts as good art [32]. The myth 'fine art is more creative than craft' is especially located in the western culture, where fine art is meant to have no function other than pleasure, whereas craft objects are evaluated as less worthy, because they serve a function, and are not 'purely' creative.

Creativity as a Complex Phenomenon

Psychologists agree on the opinion that creativity is a complex phenomenon. It involves three main aspects: person, process, and creative product. The personality and the attitude of a person seem to play an important role for being creative. A creative person usually has specific personality traits and intrinsic motivation, for instance, self-confidence, risk taking, and independence of judgment. Also some psychologists argue that creativity is correlated to intelligence, involving analytic, synthetic, and practical abilities [31]. Synthetic abilities are necessary to see problems in new ways and to escape bounds of conventional

1 Romanticism is the belief that creativity bubbles up from an irrational unconscious, and that rational deliberation interferes with the creative process [32]

thinking, and also to generate ideas. Analytic abilities are necessary to evaluate the appropriateness of ideas. Practical abilities serve to convey the ideas to other people. Knowledge plays a role for being creative: a person needs to know enough of a domain to be able to get creative insights to move this domain forward. But knowledge of a domain can also limit creativity, if a professional is only applying his expertise in the domain. Also, intelligence plays an important role for being creative [31], but it is not sufficient [28]. Furthermore a supportive, evaluation-free environment is required. Simonoton has explored cultural factors, for instance, cultural diversity, war, availability of role models and availability of resources. Also the number of competitors plays a role [31].

Simonoton also argues that creativity is a constrained stochastic process [37]. The process of being creative is combinatorial, the most total combinations produce the most good combinations. Quality of creative products is a probabilistic function of quantity of trials. Furthermore, he claims the thinking processes are unpredictable, and logically unjustifiable activities. A creative person has less predictable thoughts and behavior, because of openness to experience, diversity of interests and hobbies, and a preference for complexity and novelty. Simonoton refers to Mednick's Remote Association Test that has shown that highly creative individuals have a flat hierarchy of associations. So, for a given stimulus the person has many associations available, all with roughly equal probability. Flat associative hierarchies are more stochastic than thinking with steep hierarchies, because the outcome of any association is less predictable. Creative products are randomly distributed across the career of a creative person. Furthermore, he argues any creative process is constrained by the domain. Artistic creativity involves less constraints than scientific creativity, where products must satisfy more severe and precise evaluation criteria.

Generating ideas is called having 'insights'. It is seen as a part of the whole process of being creative. To generate ideas a person restructures her/his knowledge of the problem, for instance, creates associations and searches for analogies [31]. Margaret Boden distinguishes ideas that are psychologically creative and those that are historically creative. Psychologically creative ideas are novel to the individual's mind, whereas historically creative ideas are novel with respect to the human history [3].

Psychological Approaches to Creativity

Cognitive psychology focus on the mental processes of the individual while being creative. Psychologists have developed several models that aim at describing creativity and problem solving. Conceptual models of creative problem solving are characterized as phased or step-wise processes. These models recognize from four to six phases: finding, recognizing, defining and redefining the problem, seeking possible solutions, evaluating the alternatives, and looking for ways to apply the results [28].

Some of the first theories of creativity and problem solving were developed by Gestalt psychologists at the beginning of the 20th century. One of this early models was developed by Wallas. His stage model describes creative insights by a process consisting of five stages: preparation (focus on the problem and exploring the problem's dimensions); incubation (internalizing of the problem into the unconscious); illumination/insight (generating creative ideas from preconscious processing to conscious awareness); verification (conscious verification, elaboration and application of the ideas)[11].

In this early phase of psychological research also experiments to measure creativity were developed, for example, the matchbox-candlepins experiment that is often quoted. Nowadays, these early theories and experiments are often criticized as too heuristic and insufficient according to present day standards of psychological research.

Another model of generating ideas is the Geneplore model of Finke, Ward, and Smith [11]. The basic idea of this model is the distinction between generation (creating mental representations of the problem) and exploration (exploiting and interpreting properties of the problem) of ideas. Both phases alternate in a cyclic fashion.

Also association models were developed that describe static or dynamic relations between mental concepts [31].

Current research projects also involve computational models to simulate creativity. With respect to computation, psychologist split into two camps: one group tries to develop computational models of creative processes, the other claims, that a machine cannot be creative, hence a computational model of creativity is never sufficient, since programs base on previously determined procedures only [31].

Results of Psychological Research on Creativity

In psychology, the purpose of research is to develop an understanding of creativity as a mental (and to some extend social) phenomenon. Psychologists claim that restructuring knowledge is the key to creative problem solving. Also, the attitude plays an important role for being creative. Furthermore, psychologists have shown that people who have a lot of associations available to a particular topic generate more and also more unusual ideas. Psychological theories and models of creativity are rather abstract and descriptive than precise and prescriptive. So it is difficult to use psychological theories as a basis for developing a methodology for supporting idea generation.

2.1.2 *Pragmatic View to Creativity and Idea Generation*

The industry recognized the economical potential of creativity in the middle of the 20th century. A need for controlling and supporting creativity arose. Creative professionals were required who generate ideas for new products and services. These professionals are required to generate ideas reliably and repeatably, because companies have to sell new products continuously. Idea generation also should be transparent and justifiable, because the process of being creative should be less critically depend on a single genius. Methods of idea generation should be transferable to other people. Motivated by economy, pragmatic approaches rose up that claim to support or amplify creativity.

These approaches are also called `creativity techniques`. Creativity techniques are defined as heuristic methods to facilitate creativity in a person or group of people [12]. Creativity techniques aim at stimulating idea generation and non-linear thinking to solve problems. Some techniques focus on understanding the essence of a problem, others seek for analogies, provocations or random stimuli to inspire idea generation [25]. Creativity techniques do not investigate on causes or circumstances of creativity. Usually they do not conform to scientific standards, therefore, psychologists call these approaches 'pragmatic'.

Some of the creativity techniques have their roots in psychological theories or experiments. Wallas phases model is often used, for example, in Petty's "How to be better at creativity" (see [30]), and also experiments from Gestalt psychology are often quoted, for instance, the matchbox-candle-pins problem in Edward De Bono's book "Lateral Thinking" (see [4]).

There are several collections of creativity techniques, for instance, Van Gundy's "Techniques of Structured Problem Solving" [23]. These collections provide a classification and also instructions how to apply the techniques. Unfortunately, these instructions are often not immediately applicable in a given practical context - they may require quite a bit of imaginative interpretation. Also, there is hardly a proposal given, which technique might be used for which kind of problem. The success of a creativity technique is referred mainly to experience, abilities, and attitudes of the participants [23]. Often, the assistance of an experienced moderator is needed to successfully apply creativity techniques.

2.2 EARLIER WORK

2.2.1 *Osborn Techniques: Brainstorming and Osborn Checklist*

Alex Faickney Osborn, an advertising executive, developed the creativity technique `Brainstorming` in 1953. Brainstorming is a group creativity technique that intends to generate as many ideas as possible to solve problems creatively in an atmosphere that is constructive rather than critical and inhibitory. Osborn proposed that groups could double their creative output by using the method of brainstorming. Furthermore, he claims strict separation of idea generation and evaluation. During idea generation criticism is absolutely forbidden to provide as many different and unusual ideas as possible. Therefore Osborn set up the following rules[9]:

- `focus on quantity`: the assumption is made that the greater the number of ideas generated, the greater the chance of producing a radical and effective solution;
- `no criticism`: phases of generating ideas and criticism are strictly divided suspending judgment; a supportive atmosphere is created where participants feel free to generate unusual ideas;
- `unusual ideas are welcome`: these are thought to open new ways of thinking and provide better solutions than regular ideas, for instance, they can be generated by looking from another perspective or setting aside assumptions;
- `combine and improve ideas`: these are meant to lead to better and more complete ideas than merely generating new ideas alone;

it is believed to stimulate the building of ideas by a process of association.

Although brainstorming has become a popular group technique, researchers have generally failed to find evidence of its effectiveness for enhancing either quantity or quality of ideas generated. Because of such problems as distraction, social loafing, evaluation apprehension, and production blocking, brainstorming groups are little more effective than other types of groups, and they are actually less effective than individuals working independently [9]. For this reason, there have been numerous attempts to improve brainstorming or replace it with more effective variations of the basic technique.

Another basic group technique developed by Osborn is the `Osborn Checklist`, which is a guidance to generate ideas systematically applying a list of verbs to focus on properties and modify them [42]. The technique can be used to modify an existing product or process, but not with a completely new start up from scratch [25]. Using the verbs, questions can be asked to the participants of the group. The order of these questions is arbitrary, but all the verbs of the following list shall be processed: alternative use, adapt, change, enlarge, reduce, replace, rearrange, reverse, combine, transform.

Also the Osborn Checklist is improved, for example to the technique `SCAMPER` [43], [25] which was developed by Bob Eberle and published by Michael Michalko. The name of the technique is an acronym of the applied verbs: substitute, combine, modify/magnify, put to another use, eliminate, rearrange/reverse.

Every verb can be applied to several aspects, also a list of questions can be created out of these combinations, that leads to generation of ideas in a systematic way. But these aspects have to be found and specified by the group, they are not provided by both of the checklist techniques.

2.2.2 *De Bono Techniques: Lateral Thinking, Provocation Method and 6 Thinking Hats*

`Lateral thinking` is a term coined by Edward De Bono in 1967 [39]. De Bono defines lateral thinking as "methods of thinking concerned with changing concepts and perception". It is a method of reasoning that is not immediately obvious and about ideas that may not be obtainable by using traditional step-by-step logic [39], [4]. De Bono phrases traditional analytical and logical thinking "`vertical thinking`". It is defined as "thinking directly through and onto the current problem", whereas lateral thinking means "thinking beside the current problem", changing the point of view or the goal or some aspects of the problem. Edward De Bono wrote several books as guides to teach and train the lateral thinking abilities of people.

One of the techniques using lateral thinking is called "provocation method" (an acronym for "provocative operation")[4]. The word 'PO' is used to propose an idea, which may not necessarily be a solution, or a 'good' idea in itself, but moves thinking forward to a new place where new ideas may be produced. People in conversation could use the word 'PO' to notify others that they are intentionally making a provocative comment that should be best applied using lateral thinking techniques. The technique uses the following process scheme [25]:

1. `focus`: on simple aspects of the current problem (attributes);
2. `provocation`: modify one of the focused attributes by declining assumptions; this usually result in impossible ideas which are normally abandoned and ignored, because they are thought as 'nonsense';
3. `movement`: based upon the provocation idea a solution is searched.

Furthermore, De Bono developed the technique of "6 thinking hats", which can be used to discuss existing ideas [25]. The technique makes use of six thinking attitudes, symbolized in six hat colors:

- `white`: being objective and neutral; collecting information without any critical evaluation;
- `yellow`: being optimistic; admit advantages, chances, and hopes that can be assigned to the idea;
- `red`: being emotional; admit feelings and intuitions that occur with the idea;
- `green`: being creative; create any kind of ideas, associations, alternatives without limitations;
- `black`: being pessimistic; admit concerns, disadvantages, risks that occur with the idea;
- `blue`: being objective, abstract and leading; transfer ideas into a meta-level, direct and moderate the discussion, take care for balance of all contributions.

2.2.3 *Creativity Games*

There are also several (card) games to support creativity or to break mental blockades to create innovative solutions. Two of them are explained as representative examples.

Oblique Strategies

`Oblique Strategies` (subtitled "Over one hundred worthwhile dilemmas") is a set of published cards created by Brian Eno and Peter Schmidt in 1975. Oblique strategies is a kind of game which intends to break mental blockades occurring in difficult working situations (for example time pressure), providing alternative working strategies and methods to escape a mental black-out or panic. It is meant as reminder that the currently occurring attitude can be changed, and the obvious 'head-on' solution is often not the best possible solution [5]. The authors explain that these strategies have been derived by observation while working or recognized in retrospective [5]. One simple rule is set up: the card shall be trusted even if its appropriateness is quite unclear. Some examples of these phrases are [41]:

- State the problem in words as clearly as possible.
- Only one element of each kind.
- What would your closest friend do?
- What to increase? What to reduce?
- Are there sections? Consider transitions.
- Try faking it!
- Honor the error as a hidden intention.

Kribbeln im Kopf

`Kribbeln im Kopf`[2] is a playful creativity toolkit used in advertisement[3], developed by Mario Pricken and Christine Klell in 2005. The card game uses several basic patterns of thinking which occur in advertisement: combine, rotate, exaggerate, decompose, replace, reinterpret, metaphor, provocation, change of perspective etc. The card game is supposed to be used as stimulator for generating ideas for use in group sessions or as single user application. It aims at extending thinking patterns in stressful situations. Every card contains a abstract thinking strategy on one side and an illustrative example of this strategy on the other side. The cards have to be chosen randomly and interpreted with respect to the current task.

The game shall be used with the following rules:

- Clear definition of the goals (briefing): one main, most important statement for the product shall be formulated in a simple question, to express the most important property or purpose. Abstract terms like serious, young, innovative shall be avoided, because they are not assigned uniquely to the product.
- Distinction of fantasy and reality: within the idea generation phase, fantasy is most important and ought not to be limited by reality. Therefore, idea generation and evaluations shall be separated strictly, all ideas have to be noted down, either as text or as little sketch.
- 60 ideas in 30 minutes: the primary ideas created in the first quarter of an hour are usually common thoughts and neither original nor innovative and surprising.
- Thinking in terms of chances instead of killing ideas: critical thinking is thought as normal process, because everybody is used to it. Instead of oppressing criticism, which 'kills' ideas and constraints idea generation, those thoughts are not spoken loud, but they shall be observed consciously by oneself and used to modify the criticized idea to make it acceptable.

2 The card game is named after the book "Kribbeln in Kopf", written by Mario Pricken.
3 Advertisement is defined as creatively designed communication

- Idea development and selection: in a second phase all primary ideas shall be reviewed and developed with respect to the previously defined goal and the possibility of realization, also completely new ideas can be created out of the primary ones. The ideas are approximated to reality. In the end the most promising ideas shall be chosen and modeled to detail.

The This technique is an enhancement of the Osborn techniques. The difference to many other creativity techniques is the exemplification of the abstract thinking strategies.

2.2.4 *Morphological Analysis*

Morphological analysis is a structured technique for exploring all possible solutions to a multi-dimensional, non-quantified problem complex. The technique was developed by Fritz Zwicky. TIt intends to address seemingly non-reducible complexity [40]. The main attributes of the problem and a few most important values are identified and ordered in a coordinate system [35]. Morphological analysis is processed as follows [40]:

1. Describe the problem.
2. Analyze the possible solution's parameters: analyze possible attributes and according values, and choose the main ones.
3. Construct a morphological box: create a two dimensional matrix, transform the predefined attributes as the column header and list the corresponding values under each attribute.
4. Evaluate possible solution: determine contradictions and constraints, develop a solution space, find solutions by finding new possible combinations of values.
5. Apply the found solutions to the original problem.

2.2.5 *Synectics*

Synectics, developed by William Gordon, uses the principle of reorganizing existing knowledge to new patterns, which might solve the problem [36]. The central principle of the method is: "Trust things that are alien, and alienate things that are trusted". This encourages, on the one hand, fundamental problem-analysis and, on the other hand, the alienation of the original problem through the creation of analogies [44]. Synectics is processed as follows:

1. Analysis and definition of the problem;
2. Spontaneous solutions: for example, using Brainstorming;
3. Reformulation of the problem;
4. Creation of direct analogies: for instance, analogies occurring in nature; in the end one idea is chosen;

5. Personal analogies (identification): participants shall identify themselves with the chosen natural analogy (How does it feel to ...?); again one idea is chosen;
6. Symbolic analogies (contradictions): creating a symbolic, more generalized idea by association; chose one of the ideas;
7. Direct analogies: for example, occurring in technology;
8. Analysis of the direct analogies;
9. Application to the problem: for instance, using a Force-Fit analysis[4];
10. Development of possible solutions.

2.2.6 *Altschuller: TRIZ and ARIZ*

The theory of inventive problem solving (TRIZ) and the algorithm of Inventive Problems Solving (ARIZ) were developed by the soviet engineer and researcher Genrich Saulovich Altshuller in 1964. TRIZ is a methodology, tool set, knowledge base, and model-based technology for generating innovative ideas and solutions for problem solving, especially technical inventions. TRIZ aims to create an algorithmic approach to the invention of new systems, and the refinement of old systems. Altschuller claims that invention is the removal of a technical contradiction with the help of certain principles. To solve any inventory problem, the underlying contradictions need to be identified and an according solution principle has to be applied [1], [2]. He developed a set of 40 inventive principles and later a matrix of contradictions. Rows of the matrix indicate the 39 system features that one typically wants to improve, such as speed, weight, accuracy of measurement and so on. Columns refer to typical undesired results. Each matrix cell points to principles that have been most frequently used in patents in order to resolve the contradiction (taken from [45]).

Based upon and improving TRIZ [1], [2], ARIZ [29] was developed, which is a list of about 85 step-by-step procedures to solve very complicated invention problems, where other tools of TRIZ are not applicable[45].

TRIZ and ARIZ are mainly focusing on technical inventions, but the approaches are transfused to other problem domains. Both approaches suggest solutions for an occurring contradiction in a technical problem. The suggestions are based on knowledge derived from analysis of previously made investigations and observation of technical evolution. The approaches are criticized to lead to little improvements of existing solutions only, real innovation (a solution that is completely new) can not be developed [45].

2.2.7 *Idea Engineering*

`Idea Engineering` is a systematic engineering approach to idea generation. Idea Engineering intends to make the process of generating and

4 The Force-Fit Analysis is an comparison of advantages and disadvantages.

developing ideas more reliable, repeatable and possible to plan. The metaphor of an "idea factory" was created to emphasize the engineering character of the idea production process [25]. Idea Engineering was developed at Otto-von-Guericke University in Magdeburg in cooperation with Zephram GbR in 2005.

Idea Engineering applies and enhances common creativity techniques to idea generation techniques. Furthermore, idea generation is embedded in a more complex process of idea production that starts with analyzing a given task, and ends with the delivery of a set of feasible and appropriate ideas to solve the task. The process of idea production is also an enhancement of the idea generation process of Brainstore AG, developed by Nadja Schnetzler [27], [33]. Idea Engineering has determined the production chain as follows [21],[25]:

1. `briefing`: fix all preconditions of the idea production process (this means, specify the task, collect all necessary information: background of the customer and the order, a declaration of the goal with respect to the goals of the customer, an accurate definition of the task, determine criteria for success and constraints);

2. `idea generation`: stimulate the participants using inspiration; stimuli are suggestive ideas to help the participants creating primary ideas; the stimuli can be obvious, exotic or unreal;

3. `generation of primary ideas`: produce 100 to 300 primary ideas in idea generation shifts; primary ideas are rudimentary ideas for solutions;

4. `selection`: preselect and reduce primary ideas down to the 5 to 20 best ones; withing a filtering process akin ideas are combined and the best primary ideas are chosen;

5. `idea processing`: develop proposal solutions out of the best 5 to 20 primary ideas by using helping tools (for example, completion or improving lists);

6. `quality control`: check solutions by general criteria, constraints, criteria for the success, goals of the customer

7. `discussion`: present and discuss the recommended solutions with the customer: solution ideas are compared and evaluated with respect to implementation and success criteria (for example costs, level of innovation, potential for success, market opportunity, political factors);

8. `ranking`: sort recommended solutions by ranking criteria (for example implementation costs, potential for success, potential for astonishment);

9. `delivery`: deliver the final recommended solutions to the customer.

Idea Generation Techniques

In the context of Idea Engineering several common creativity techniques have been analyzed. Goers and Horton claim that there are three independent parameters of any applied idea generation technique: technique, appearance and staging, defined as follows [21]:

TECHNIQUE (ALGORITHM) : abstract specification of steps to the goal that does not contain details of implementation.

APPEARANCE : design and presentation of the technique (for example used media, size of the group, kind of moderation) and relevance (effects of synergy or anti synergy, efficiency).

STAGING : the story according to a technique (for example using the metaphor of the idea factory, a play or using requisites) is important for the motivation and immersion of participants; this is aimed to free participants from inhibitions and blockades and makes the idea factory an experience.

A large amount of creativity techniques have been discovered as variations of the three main techniques: association, random and provocation methods [25]. The core principle of any idea generation technique applied by Idea Engineering is to change the perspective to the original task, to find more unusual ideas. Idea generation takes place in moderated IGSs. The phenomenon creativity is mainly interpreted as the result of people working together professionally (using the effect of synergy). An atmosphere supporting creativity and the change of perspective to the problem are assessed as significant for successful idea generation [25]. The change of perspective is performed via viewing specific attributes: people, places, parts, processes, parameters, policies, purpose, problems. Properties of these attributes are (a) being conservative or radical, (b) obvious or far-fetched, or (c) general or specific [25].

2.2.8 *Minerva-Centaur Design Approach*

`Minerva-Centaur Design Approach` is an engineering approach for designing systems and products professionally, developed by Kees van Overveld. He defines professional designing as "taking decisions for the future benefit of one or more identified customers or `stakeholders`" [47], [26]. Any people who are affected by the decisions made during the design are stakeholders of the innovative design task. The Minerva-Centaur Design approach comes with a set of software systems that can support the methodology.

Van Overveld claims that creating and designing innovative products or services involves both structured and analytic thinking (so called Minerva-type), but also creative, intuitive and synthetic (so called Centaur-type) thinking abilities. The Minerva-Centaur Design Approach intends to develop a coherent system of thinking tools that bridge the gap between both kinds of thinking in solving a task [47]. Van Overveld advocates the distinction between implicit, intuitive thinking and explicit, rational thinking, which are related dynamically and transitively. The Minerva-Centaur Design Approach aims at making design more explicit. Decisions made during any design shall not be made unconsciously, based on intuition only, but be made consciously and be justifiable and comprehensible for other people. Intuition and idea generation, which are usually thought of as preconscious, are recognized as valuable in the beginning of any synthetic or analytic analysis. But the emphasis of the Minerva-Centaur Design Approach is on a rational and explicit analysis and completion of the ideas, generated in the beginning. Minerva-Centaur Design Approach structures any design process in the following three phases (taken from [47]):

1. `idea generation`: generate a preferably large number of options (ideas), which are as different as possible to each other;
2. `selection`: select the most plausible options by justified, preferably explicit, and if possible objective criteria; the designer has to be able to explain why he has chosen one option and rejected another; during the selection phase, the space of all ideas is reduced to the very few very best ones;
3. `detailing`: (mathematical) modeling of the preferred option, including defining and modeling of quantitative details of the selected idea.

Systematic Idea Generation

In the first phase, different ideas are generated. There is no specific method proposed to generate the first initial ideas. The Minerva-Centaur Design Approach is not committed to a particular method to support idea generation. The user may apply his/her preferred creativity techniques. For generation and analysis of ideas the tool "Assist" is proposed. It contains of a grammar-based method to support idea generation, but no built-in grammars are part of the system. Prior to using a grammar for stimulating creative thinking in a particular domain it has to be provided, for example, by a trained moderator.

The ideas have to be distinguished and classified according to relevant attributes, hence their name, "classifiers". Any classifier has to have a predefined discrete range of values which might occur. By introducing classifiers, and classifying items with respect to these classifiers, an ontology of the domain is built. The classifiers are required to be independent and operational, that means they have to be relevant for all items of the domain. The classifiers span a space of the ontology. The ontology can be complemented by new combinations, generated by the system. Whether these suggested combinations are meaningful, the user has to decide. By this mechanism the space which is spanned by the ontology is explored. The correlation between the classifiers is computed, so that important and independent attributes can be discovered.

2.3 summary of earlier work and state of knowledge

Psychologists claim that the personality and the attitude of a person play an important role for being creative. To solve a creative problem, people restructure their knowledge of the problem, create associations and search for analogies. 'Pragmatic approaches' were developed that aim at supporting idea generation and creative problem solving. My means of this approaches it was shown that idea generation can be stimulated (inspired) and supported, and that creativity is not only a matter of talent.

Some significant approaches were presented in the previous sections. This approaches regarding idea generation and creative problem solving are summarized below.

BRAINSTORMING : Supporting idea generation by separating idea generation and evaluation.

OSBORN CHECKLIST : Supporting idea generation by modifying attributes of the problem with respect to verbs of the checklist.

LATERAL THINKING : Supporting idea generation by applying several methods of 'thinking beside the problem' by means of changing the perspective to the problem and inverting goals and aspects of the problem.

PROVOCATION METHOD : Supporting idea generation by proposing unrealistic and provocative ideas.

6 THINKING HATS : Supporting discussing and developing ideas by assuming specific thinking attitudes.

OBLIQUE STRATEGIES : Supporting idea generation by providing alternative, generic working strategies.

KRIBBELN IM KOPF : Supporting idea generation by providing alternative, generic thinking strategies and examples.

MORPHOLOGICAL ANALYSIS : Supporting exploration of possible solutions by analyzing main attributes of the problem.

SYNECTICS : Supporting idea generation by creating analogies and 'alienating' aspects of the problem.

TRIZ/ARIZ : Proposing solutions by analyzing and compensating basic contradictions of the problem.

IDEA ENGINEERING : Supporting idea generation by means of a directed change of perspective and further processing of generated ideas.

MINERVA-CENTAUR DESIGN APPROACH : Supporting the analysis and exploration of ideas; providing detailed modeling and improvement of ideas.

3 AN ALGORITHMIC APPROACH FOR GENERATING INSPIRATIONAL SENTENCES

> Creativity, it has been said, consists largely of re-arranging what we know in order to find out what we do not know.
>
> *(George Kneller)*

In this chapter the concept of an algorithmic approach for supporting idea generation is introduced. First, introspective observations are presented that have led to the approach. Requirements are set up. After this a first attempt and the basic concept are introduced.

3.1 Introspective observations leading to this approach

The goal of this thesis is to support people to generate more unusual and therefore innovative ideas. This goal is based on some assumptions. First, ideas generation can be supported. Second, I assume that unusual ideas are more likely to lead to innovative solutions than common ideas. Both assumptions I have in common with other supporting approaches that were introduced in section 2.2. Furthermore, I assume that a set of more divers ideas contains more unusual ideas than a set of very similar ideas. To stimulate the generation of more unusual ideas some mental work is necessary. Just generating more ideas is not sufficient, because the ideas could be 'straightforward generalizations'.

An idea is a new thought. Ideas regarding a problem do not necessarily have to be solutions for it. They can be unrealistic, inappropriate and weird. A 'good' idea leads to a solution in the end. An innovative idea leads to a novel solution for a problem.

3.1.1 *Inspiring Idea Generation*

The human mind is preconditioned and trained to filter any idea with respect to relevance and appropriateness. In general, this mechanism is helpful to focus on a task, and to do the right and most important things at the moment they are necessary. In the process of solving open problems (for example problems, where no a priori solution is available), this mechanism is counterproductive, because several ideas are dismissed on the basis of prejudices. A typical phenomenon occurs. It seems that the problem owner is 'blinded' by his knowledge of the problem domain, so that he is not able to generate innovative ideas[1]. The problem owner is not able to break out of well established thinking patterns and preconditioned thinking according to a problem.

1 In the German language this phenomenon is called 'Betriebsblindheit'

Creativity techniques in general try to avoid these mechanisms, for instance, by separating idea generation from evaluation of those ideas, and guiding through detours of thinking to solve a problem. Psychologists call this kind of thinking ’divergent’, Edward De Bono has created the name ’lateral thinking’ for this. Every creativity technique contains one or more divergent thinking strategies.

Idea generation for design tasks often takes place in moderated IGSs. In this sessions the moderator inspires the participants to generate ideas, for instance, by applying creativity techniques. Especially to inspire the generation of unusual ideas requires the moderator’s creative skills.

Inspiration for generating ideas can be observed in more common situations, too. Talking to outsiders who are not deeply involved in the particular problem domain, often helps to get fresh ideas. The questions and suggestions of a interviewer who tries to understand and scrutinize a problem can make the problem owner aware of certain limitations in his thinking and assumptions about the problem that are taken for granted. This interviewer applies unconsciously some thinking strategies.

A tool that synthesizes problem-related sentences, similarly to an interviewer or moderator who scrutinizes and restructures knowledge of a certain domain, hopefully will inspire people to get more unusual ideas.

3.1.2 *Inspirational Sentences*

According to the fictional problem, to extend the service of a shop of garden facilities, sentences were created that aim at inspiring the problem owner to generate ideas for solving the problem. The full list of these questions and suggestions is listed in appendix A. The most interesting sentences are the following ones:

Why don’t you take a green hat view to look at the contracts with lawn-mower retailer?

This question invites to view the problem with a special attitude[2] and focus on a special aspect of the domain, namely the contracts between the shop of garden facilities and its lawn-mower retailer. To change the mood according to the problem has an effect similar to assuming the role of an actor, this allows a participant to behave deviant and to propose unusual ideas.

What would the pope buy in your shop?

This question invites to change the perspective to the problem by substituting the problem owner with some famous character[3].

Someone’s children want to work in the garden, what kind of tools would you give to them?

In this question, the usual customers are substituted by a the very special target group, namely ’children’. Generalization and specialization are forms of substitutions that occur often in inspirational sentences. In this case, ’customers’ is generalized to ’people’, and ’people’ is specialized to ’children’. To focus on abilities and special needs of particular

2 In this question, the technique ’6 thinking hats’ is applied.

3 In this question, the technique ’Mister X’ is applied.

target groups might give rise to new services or tools.

Think about cemeteries or balconies, what are the differences to work there compared to ordinary gardens?
This question focuses on the purpose of the domain, for example 'selling tools for working in the garden'. Also, a substitution happened: the most likely location, namely 'gardens' is substituted by other options, namely 'cemeteries' and 'balconies'. These options are unlikely; one normally would not think of these options. That is what makes them interesting as inspirations in an IGS.

Assume it is very hot, how could lawn-mowing be refreshing?
Normally 'lawn-mowing' is done on sunny days; it makes you hot and tired. It would be strange, and therefore interesting, to think of options where the opposite would be the case. So, the result 'being hot and tired' is substituted by its opposite, namely 'being refreshed'.

Imagine there is no electricity available in a garden, what kind of tools would not work any more?
This question focuses on tools and specific properties of these tools, namely the actuation that requires the resource electric power. It is unusual to discard assumptions, for instance that elementary resource are available.

What does a shop of garden facilities have in common with a hospital?
In this question two domains are associated that are very different, therefore, this question is interesting.

How could you take advantage of the spare capacity on the winter?
This question focuses on a negative circumstance of the domain: in winter season shops of garden facilities have a spare capacity in selling tools and maintenance. To see the bright side of this circumstance might open the view to new services. This is a substitution of attitude to this particular circumstance.

In most of these example sentences, specific aspects of the problem are focused. Characteristics and properties are substituted (substitution means: exchanging one element by an alternative element) or scrutinized. Typical locations, customers or target groups are substituted by alternatives, for instance, opposites, specializations, similar or related items. Also the 'default' attitude is substituted by a particular one. Assumptions, properties and attitudes (in this case: a situation is assessed as an advantage or disadvantage) that are taken for granted are scrutinized. The last kind of inspirational questions contains an association of things that are very different.

3.1.3 *Principles of Inspirational Sentences*

Analyzing several examples of inspirational questions and suggestions led to the following principles:

1. `scrutinize` knowledge of the problem domain taken for granted;
2. `focus` on parts and aspects of the problem domain; also focus a few 'steps' into details of the problem domain;
3. `substitute`
   a) more abstract objects by more concrete and specialized objects and/or

b) objects of the problem domain by opposite, different, similar or related objects;

4. `associate` different objects.

3.2 REQUIREMENTS

In this thesis, I want to develop an approach for synthesizing inspirational sentences that are similar to sentences created by an interviewer scrutinizing and reconceiving the problem. Example sentences from different problem domains were analyzed. The discovered principles describe patterns of this sentences that are independent of the problem domain. So, inspirational sentences implement generic principles.

Also, all sentences focus on very specific aspects of the problem. And these sentences are formulated very precisely with respect to the problem. So, these inspirational sentences are sufficiently specific and precise, so that they can be applied to the problem without an interpretation.

The last property of these inspirational sentences: all sentences are meaningful with respect to the problem.

So, the following requirements for the approach are set up:

1. The methodology for synthesizing inspirational sentences has to be generic, so that it can be used for problems of arbitrary domains.

2. This methodology has to synthesize sentences that are in some sense meaningful to a specific problem.

3. The methodology has to synthesize sentences that are sufficiently specific and precise, so that the user should not have to think too hard about the interpretation of the sentences.

3.3 AN APPROACH USING A GRAMMAR

The first attempt to synthesize inspirational sentences was to use a grammar. This grammar has be sufficiently generic, so that it can be used for problems of arbitrary domains, and it has to generate meaningful and precise sentences that are related to the problem domain. If it is possible to generate inspirational sentences regarding a problem by applying simple syntactical rules, it would not be necessary to build an advanced model of the domain knowledge. This idea was inspired by the ELIZA program, which could successfully ask people questions with respect to a topic, without further modeling of knowledge (see: [48]).

In computer science a `grammar` is defined as follows [34]: a grammar is a 4-tuple $G = (V, \Sigma, P, S)$:

v : The finite set of variables, called nonterminals.

Σ : The finite set of terminals, called the alphabet: $V \cap \Sigma = \emptyset$.

p : The finite set of production rules; $P \subseteq (V \cup \Sigma)^{+} \times (V \cup \Sigma)^{*}$.

$s : s \in V$ is the start variable.

Initialized with the start variable, production rules are applied without any restriction until a terminal is reached. For example, assume the alphabet $\Sigma = \{a, b\}$ and the production rules:

$$1) S \Rightarrow aSb$$

$$2) S \Rightarrow a$$

. The production rules are applied as follows (using the sequence of rules: 1, 1, 2):

$$S \Rightarrow aSb \Rightarrow aaSbb \Rightarrow aaabb$$

3.3.1 *Generation of Inspirational Sentences by Means of a Grammar*

A naive approach to present inspirational sentences is to use a finite set of predefined questions and suggestions. Randomly one sentence after another is chosen. This approach is used in some creativity techniques work, for example in creativity games (see 2.2.3). For this approach, all possible sentences have to be made by hand. It is not possible that any new questions could emerge, if it is not added explicitly. Also the sentences need to be formulated very generally and to fit to arbitrary problems. Also some sentences might not fit to all kinds of problems, because the characteristics of this problems are not taken into account. In example, the suggestion: "Magnify the most difficult details" (taken from Oblique Strategies [5]) is way to abstract, and therefore it is difficult to apply to a specific problem. The user has to think quite a bit to apply this suggestion to get ideas for the problem, for example to 'get a new idea for a birthday present' or to 'extend the service of a shop of garden facilities'. This approach does not meet the requirement to generate precise inspirational sentences. To have precise sentences, these sentences have to be generated for every domain and the resulting set of sentences would not be generic any longer.

Another option to build a grammar is to deconstruct inspirational sentences to extract terminals, nonterminals and production rules. The following examples show the production rules that were created by deconstructing certain inspirational sentences.

Magnify the most important details (Oblique Strategies):
<obliqueStrategies> ::= <magnifyQuestion> | <otherStrategies>
<magnifyQuestion> ::= Magnify <details>
<details> ::= <important details> | <non important details>
<important details> ::= size | volume | weight | material
<non important details> ::= color

Why don't you take a green hat looking at the contracts with your lawn mower retailer (6 hats):
<6hats> ::= Take a <hat color> looking at <domain aspects>
<hat color> ::= <color> hat
<color> ::= red | green | blue | yellow | white | black
<domain aspects> ::= <contract aspects> | <other aspects>
<contract aspects> ::= the contracts with your <contract related people>

<contract related people> ::= <retailer> | <customer> | <staff>
<retailer> ::= lawn mower retailer | <other retailers>

What would the pope buy in your shop? (Mister X)
<misterX> ::= What would <famous person> <domain activity> <domain location>?
<famous person> ::= the pope | Mother Theresa | <other people>
<domain activity> ::= sell | buy
<domain location> ::= in the shop | at the cash point | <other locations>

3.3.2 *Example Sentences*

For the problem of extending the service of a shop of garden facilities, some grammars have been developed. The most useful one is listed in appendix B. Using this grammar, inspirational sentences were generated. Some examples are listed below, some more examples are attached appendix B).

- *How could you take disadvantage of satisfying your customer's needs?*
- *How could you extend your business?*
- *Imagine you are Obi-Wan Kenobi at a garden.*
- *How could you sabotage your rivals' shop?*
- *Think about your staff.*
- *What would the pope buy in the shop?*

This grammar produces many sentences that are precise and meaningful with respect to the problem, but it is domain specific. So, it does not meet the requirement to be generic. To have a generic grammar all domain specific terminals and nonterminals were remove.

- *Imagine you do <domainRelatedActivity> <domainRelatedLocation>.*
- *Think about you.*
- *Why don't you take a green hat looking at <domainRelatedObject>?*
- *What problems do have Obi-Wan Kenobi with doing <domainRelatedActivity>?*
- *What if <domainRelatedObject> would be on a coffeecup?*
- *What if a teaspoon would be on a coffeecup?*

This grammar produces generic sentences that contain some nonterminals which are placeholder for domain related terms. To generate sentences that are precise and meaningful with respect to the current problem, domain related terminals have to be added, for instance by means of a script. But selecting arbitrary domain related terminals does not necessarily produces inspirational sentences. For instance, replacing <domainRelatedActivity> by 'gardening' and <domainRelatedLocation> by 'in the garden', produces the sentence: *imagine you do* *gardening in the garden.* This is just an ordinary fact and therefore, it is not inspirational. The substitutions in inspirational sentences are not arbitrary. In inspirational sentences, ordinary things are substituted by certain alternatives, for instance, rare specializations, opposites, similar or related things. This are semantic relations between domain objects. These semantic relation cannot be expressed in terms of a generic grammar.

By means of the grammar, some inspirational questions were generated which are similar to the example questions. But also a lot of meaningless and nonsense questions were generated.

3.3.3 *Intermediate Conclusion*

Using grammar only is limited very soon. Either the grammar has to be domain specific to generate sentences that are related to the domain, but then the grammar cannot be used for arbitrary problems. Or the grammar is independent of the domain, but then it generates only generic 'phrases', that are very abstract and require interpretation. The more generic the grammar is the more 'phrases' and nonsense sentences are generated. A grammar only approach is not sufficient to generate reliably sentences that are precise and meaningful with respect to the problem.

The structure of inspirational sentences can be separated into two parts: grammar and knowledge. The grammar can be generic and depends on the natural language. It describes how a sentence is build properly. The knowledge is either problem specific or more generic world knowledge.

So, I came to the following intermediate conclusion: to synthesize meaningful sentences that are also inspirational requires knowledge of the problem domain.

3.4 AN APPROACH USING AN ONTOLOGY

There are several possibilities to model knowledge. Knowledge representation systems are a research area on their own. Most systems are quite complex and domain specific. For this approach, a generic, flexible and extendable method is required to represent the knowledge of arbitrary problem domains.

The `Minerva-Centaur Design Approach` already implements a generic knowledge representation, namely an ontology. The Assist system classifies items of an arbitrary domain regarding specific attributes, called classifiers, and creates an `ontology` of this items. Such an ontology represents semantic information in a generic structure. Such an ontology seems to be feasible to represent a lot of precise domain knowledge generically. Before this representation is explained, the term 'ontology' needs to be defined.

The term 'ontology' is used in arbitrary professions, so there are also different definitions of an ontology[4]. Some alternative definitions of an

4 The term ontology has its origin in philosophy, where it is the name of a fundamental branch of metaphysics concerned with existence. In philosophy an ontology is the study of being or existence. It seeks to describe or posit the basic categories and relationships of

ontology in terms of computer science are given in appendix C. I prefer the definition of Thomas Gruber ([22]):

> An ontology is an explicit specification of a conceptualization. A conceptualization is an abstract, simplified view of the world that I want to represent.

An ontology is a description of the concepts and relationships between those concepts [17].

Ontologies generally describe [17]:

- Individuals: the basic or 'ground level' objects
- Classes: sets, collections, or types of objects; a class is a set of objects, with all objects being a subset of objects of their kind, having a specific classifying attribute in common.
- Attributes: properties, features, characteristics, or parameters that objects can have and share
- Relations: ways that objects can be related to one another

3.4.1 *Conceptual Model of an Ontology*

The ontology has to represent detailed knowledge from arbitrary domains. So, the ontology is required to store domain specific knowledge using a generic structure. Semantic information can be expresses generically in terms of concepts, attributes and values that are related to each other. This can be done as follows: for instance the domain 'means for transportation' contains several items: 'bicycle', 'tram', 'car', 'passenger plane', 'sailing boat', 'submarine', 'sledge' and 'lift'. These objects are called `concepts`. Every concept has specific `attributes`. For instance, a 'car' has an 'actuation', a 'maximum speed' and a 'maximum number of passengers'. Every attribute has a specific range of `values`. For instance, the range of the attribute 'actuation' are the values: 'engine', 'physical power', and 'wind energy'. This structure of concepts, attributes and values, which are related to each other, forms the ontology.

The conceptual model of such an ontology is a directed graph. A directed graph is a 2-tuple G=(V,E): V is the set of elements, called vertices [6]. E is the set of ordered pairs of vertices, called edges: $E \subseteq V \times V$. The ontology graph contains three kinds of vertices, namely concepts, attributes and values. The edges of the graph are the relations between those elements in the ontology. The principle of this ontology structure is visualized in figure 1.

---

being or existence to define entities and types of entities within its framework. Ontology can be said to study conceptions of reality [16].
In both computer science and information science, an ontology is a data model that represents a set of concepts within a domain and the relationships between those concepts. It is used to reason about the objects within that domain [17]. According to Thomas Gruber at Stanford University, the meaning of ontology in the context of computer science, is "a description of the concepts and relationships that can exist for an agent or a community of agents." He goes on to specify that an ontology is generally written, "as a set of definitions of formal vocabulary." [17]

3.4.2 *Generation of Inspirational Sentences by Means of an Ontology*

Inspirational sentences can be expressed in terms of concepts, attributes and values. In example, the inspirational sentence: *Imagine customers of your shop of garden facilities would be animals* can be expressed as follows: *Imagine <attribute> of <concept> would be <alternative value>*. The 'shop of garden facilities' is a concept that has an attribute 'customers'. The usual customers of the shop are substituted, in this case by the alternative 'animals'. The required knowledge to generate this sentences can be represented using the ontology as follows: the 'shop of garden facilities' becomes a concept that is related to other concepts, in example 'business', 'shop', 'building'. For each concept a sufficient number of attributes needs to be specified, in example 'purpose', 'service', 'staff' and so on. A 'shop' in general has an attribute 'customers', so also a 'shop of garden facilities' has 'customers'. The value for the attribute 'customers' is 'people'. 'People' also occurs as a concept. 'Men', 'women', 'children' and 'handicapped people' are special kinds of people. Also 'people' are a special kind of 'living beings'. 'Animals' are another special kind of 'living beings'. By substituting the value 'people' of the attribute 'customer' by the alternative value 'animals', a surprising new combination of existing knowledge is created. This combination can be transformed into a comprehensible sentence, in example using the sentence pattern above, and presented to a user. The subgraph of an ontology representing this example is illustrated in figure 2.

The example ontology provide generating some more inspirational sentences: *Imagine the 'staff' of the 'shop of garden facilities' would be 'children'/'women'/'handicapped people'.* Here, the value of the attribute 'staff', namely 'people', is substituted by the value 'children'. The concepts 'people' and 'children' (or 'women' or 'handicapped people') are related by a `specialization_of` relation.

In section 3.1.3 principles of inspirational sentences were developed: scrutinizing of existing knowledge, focusing on aspects, substituting objects by alternatives and associating sufficiently different objects to each other. An ontology seems to allow to realize these principles. The principles of inspirational sentences can be mapped to structures and operations on the graph:

1. scrutinize knowledge: negate existing relations between objects;
2. focus on aspects of the problem: navigate between the concepts, attributes and values via relations;
3. substitute more abstract objects by more specialized ones: find concepts that are related to each other by specialization and abstraction-relations
4. substitute objects by opposites, similar or related objects: find alternative (opposite, similar, related) concepts or values
5. associate objects that are sufficiently different: find sufficiently different concepts

The implementation of these principles will be given in detail in section 4.3.1. Especially finding interesting alternatives and sufficiently different objects seem to be challenging.

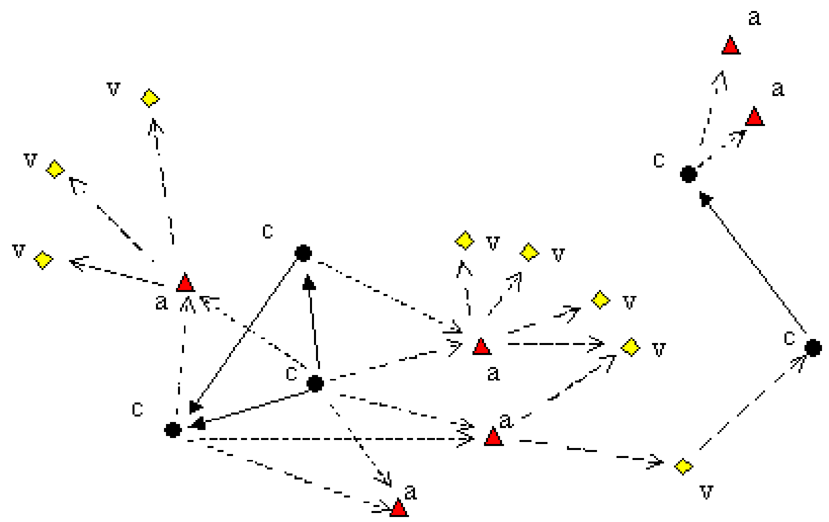

Figure 1. The generic structure of the ontology: the conceptual model of the ontology is a directed graph. Vertices of the graph are concepts (black dots), attributes (red triangles) and values (yellow rhombi). The edges of the graph are several different relations between the concepts, attributes and values in the ontology.

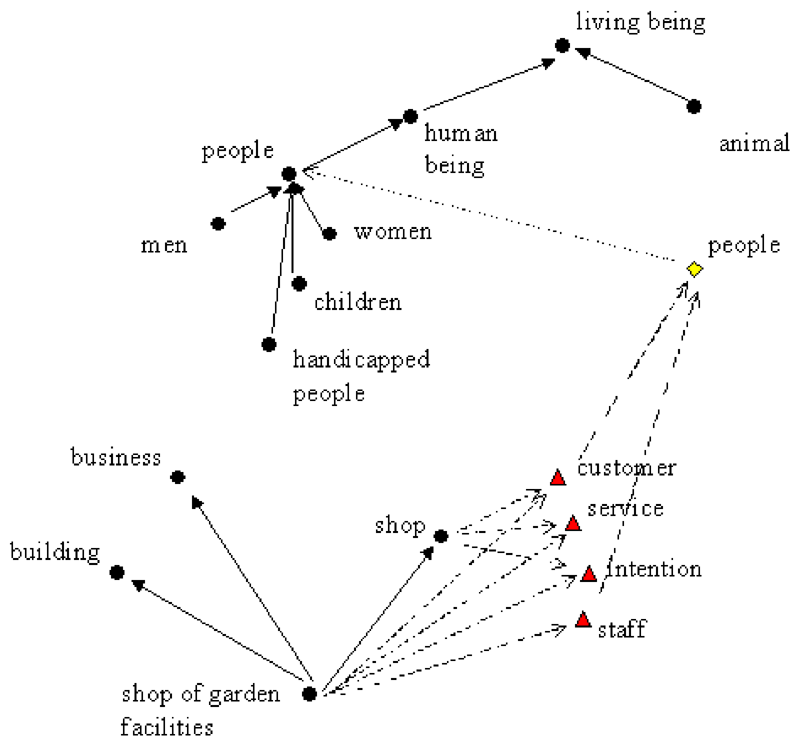

Figure 2. Subgraph of an ontology containing knowledge of the domain of the 'shop of garden facilities'.

The general procedure to synthesize inspirational sentences using an ontology is the following:

1. Build up the ontology.
2. Generate new combinations and associations of elements in the ontology; scrutinize existing relations between elements in the ontology.
3. Create comprehensible sentences of the combinations.

3.5 CHAPTER SUMMARY

In this thesis an approach will be developed that aims at inspiring people to generate more unusual ideas by means of inspirational questions and suggestion that are related to the problem. In this chapter the concept of this approach was explained. The methodology is required to be generic in order to be applicable to arbitrary problems, and it has to generate meaningful and precise sentences. It has turned out that a grammar-based approach for generating such inspirational sentences does not meet this requirements. For generating meaningful and precise sentences it is necessary to restructure domain knowledge. This knowledge can be represented generically in an ontology. By means of operations on this ontology it is be possible to synthesize inspirational sentences.

4 DESIGN OF AN ONTOLOGY-BASED MODEL

> Since we can't deal with reality, we better get good at modeling
>
> *(Kees van Overveld)*

In this chapter, the ontology-based approach to support idea generation will be described in detail. First, the structure of the ontology will be defined and explained. After this, it will be described how the ontology can be build up and how the ontology can be used to synthesize inspirational sentences.

The ontology is the main part of the approach. It is required to be generic, so that is is possible to store knowledge from arbitrary domains. Knowledge stored in the ontology serves for generating inspirational sentences. The ontology-based approach is intended to synthesize sentences that are sufficiently specific and precise, so that the user should not have to think too hard about the interpretation of the sentence. Furthermore, these sentences should be in some sense meaningful in relation to the specific problem.

4.1 A FORMAL MODEL OF THE ONTOLOGY

The ontology is defined formally and informally. The informal description of the structure explains the meaning; the formal definition describes the ontology precisely, and therefore, serves as a base for the implementation of the approach. The formal model is build up using naive set theory, this means, well-defined and finite sets of objects are assumed.

Conceptually the ontology is a directed graph, as already explained in section 3.4.1. The ontology contains three kinds of elements (vertices of the graph), namely concepts, attributes, and values, and a number of different kinds of edges, which represent the relations between those elements.

4.1.1 *Elements in the Ontology*

`concept` c : A concept is an object of the physical world or immaterial world of thoughts and social societies, for example 'tree', 'marriage', or 'an idea for a birthday present'. The set of all concepts in the ontology will be denoted by C.

`attribute` a : An attribute is a property of a concept that describes the concept. For example, 'color' is an attribute for a visible concept that is colored. The set of all attributes in the ontology will be denoted by A.

`value` v : A value is the result of mapping an attribute to a concept. A concept together with an attribute forms a variable, which can assume a value. For instance, 'red' is a value for the attribute 'color'. Mapping the attribute 'color' to the concept 'tomato' produces the value 'red'. The set of all values in the ontology will be denoted by V.

4.1.2 *Relations in the Ontology*

Common ontologies are usually very specific to the domain they represent. These ontologies contain relations like 'is-brother-of' or 'is-married-to' [38]. The ontology-based approach is required to be generic, therefore, the ontology needs to be generic, too. It is possible to express knowledge from any domain in terms of `concepts`, `attributes` and `values` that are related to each other. Such an representation of knowledge is independent of the problem domain.

A set of generic relations is discovered. Some of these relations are based on the Minerva-Centaur-Design Approach (see section 2.2.8), others are based on the analysis of inspirational sentences (see section 3.1.2).

Every relation has one or more corresponding functions, depending on which elements of the ontology occur in the relation. If a function produces more than one element, these functions will be set-valued functions[1]. For example, the 'color' of a 'car' can be 'red' and 'blue', if the car is colored in multiple colors.

`signature` : The relation between a concept and the set of attributes that describe this concept is called `signature` of that concept. The concept 'car' can be explained using attributes 'purpose', 'actuation', 'owner', 'maximum speed', 'cylinder capacity', and so on. The corresponding set-valued function that maps a concept to a set of attributes is called ϕ.

$$\phi : C \Rightarrow \wp A$$

`domain` : The relation between an attribute and the set of concepts, where this attribute can be applied to, is called `domain` of the attribute. The attribute 'color' can be applied to material and visible concepts, for example 'car'; an immaterial 'idea' has no 'color'. The corresponding set-valued function that maps an attribute to a set of concepts is called ψ.

$$\psi : A \Rightarrow \wp C$$

`range` : The relation between an attribute and the set of values that can be assumed to this attribute, is called `range` of the attribute. For instance, the attribute 'purpose' can assume the values 'supporting work', 'feed hunger', 'further development'. The set-valued function that maps an attribute to all values that can be assumed to this attribute is called ρ.

$$\rho : A \Rightarrow \wp V$$

1 A set-valued function is a generalization of a function that does not produce a single, unique element, but rather a set of elements.
Therefore, the notion of 'power set' $\wp$ is used in the formal definition of these functions. The power set of a set S is the set of all subsets of S

`fact` : The relation between a concept, an attribute from the concept's `signature` and a value that can be assumed to this variable, is called `fact`. For instance, the concept 'car' can be described using an attribute 'purpose'. The variable 'purpose' of a 'car' can assume the values 'transport things' and 'transport people'. The corresponding set-valued function that maps a concept and an attribute that is in the `signature` of the concept to a set of values is called θ.

$$\theta : C \times A \Rightarrow \wp V$$

$$\forall a \notin \phi(c) : \theta(c, a) = \emptyset$$
$$\forall a \in \phi(c) : \theta(c, a) \subseteq \rho(a)$$

`value_is_concept` : A value can also occur as concept, for example 'people' can occur as a value that can be assumed to the attribute 'customer', and it can also occur as a concept. 'People' is a possible value for the attribute 'customers' and also it is a concept. The relation that expresses that a value and a concept refer to the same thing is called `value_is_Concept`. The corresponding function that maps a value to the corresponding concept, is called μ.

$$\mu : C \Rightarrow V$$

`opposite_of` : Values can oppose each other with respect to a specific attribute. For instance, the value 'light' is the opposite of 'dark' according to the attribute 'lighting', but 'light' is also the opposite of 'heavy' according to the attribute 'weight'. The relation between two opposing values with respect to a specific attribute is called `opposite_of`. The corresponding function that maps a value to the opposite value, regarding a specific attribute, is called ω.

$$\omega : V \times A \Rightarrow V$$

$$\forall v_i, v_j \in \rho(a) : (\omega(v_i, a) = v_j) \land (\omega(v_j, a) = v_i)$$
$$\forall v_i \in \rho(a) \land v_j \notin \rho(a) : \omega(v_i, a) \notin v_j$$
$$i \neq j; i, j = 1, 2, ...$$

A common way to describe objects of the world is to create classes[2] of objects. The human mind is familiar to classification and ordering: the first ontologies of objects of the world have been developed in ancient Greece [16]. Usually objects are classified and arranged using inheritance. A partial ordering is a common way to deal with inheritance. Inheritance between concepts can be described in two directions, top down or bottom up. Top down means a partial ordering from abstraction to specialization, bottom up means a partial ordering from abstraction to specialization. These relations form a lattice[3] of concepts.

2 A class is an abstract description of a set of objects of the world.
3 A lattice is a partially ordered set that is: a set where an ordering relation exists between the elements of some of the pairs, but not necessarily for all the pairs.

`specialization_of` : A concept can be a specialization of several other concepts, if it contains at least all properties of the other concepts. For instance, a 'cabriolet' is a special kind of 'car', because it contains all attributes of a 'car. Additionally it has the specific fact that it has a 'convertible' 'top'. A 'cabriolet' is also a special kind of 'means for transportation', because it is used to 'transport' 'people' and their 'luggage'. The relation between a concept and a set of other concepts, where the first concept contains the `signature` of the second concepts, and all facts of the first concept regarding attributes of the abstract concept's signature are contained in the second concept, is called `specialization_of`. The corresponding set-valued function that maps a specialized concept to a set of abstract concepts, such that the `signature` of the specialized concept contains the `signature` of every abstract concept, and, for every attribute in each `signature` of an abstract concept, the collection of `facts` of the specialized concept is contained in the collection of `facts` of the abstract concept. This function is called σ.

$$\sigma : C \Rightarrow \wp C$$

$$c_i \in \sigma(c_j) \Leftrightarrow \varphi(c_j) \subseteq \varphi(c_i) \land$$

$$(\forall a : a \in \varphi(c_j) : \theta(c_j, a) \supseteq \theta(c_i, a)); i, j = 1, 2, ...$$

`abstraction_of` : Similar to the `specialization_of` relation, a concept can be an abstraction of several other concepts. The relation between a concept and a set of other concepts that all have the properties of the abstract concept in common, is called `abstraction_of`. The corresponding set-valued function that maps an abstract concept to a set of specialized concepts, such that the `signature` of each specialized concept is at least the signature of the abstract concept, and the `facts` of the specialized concept are at most the fact of the abstract concepts regarding to attributes of the abstract concept's `signature`, is called χ.

$$\chi : C \Rightarrow \wp C$$

$$c_j \in \chi(c_i) \Leftrightarrow \varphi(c_j) \subseteq \varphi(c_i) \land$$

$$(\forall a : a \in \varphi(c_j) : \theta(c_j, a) \supseteq \theta(c_i, a)); i, j = 1, 2, ...$$

Furthermore, concepts can be akin to each other with a specified degree of kinship, or they can be similar in some respect. For example, members of a family are are akin to each other: children, parents and siblings of a person are relatives of degree one; grandparents and grandchildren, and also uncles and aunts are relatives of degree two. The concepts 'apple' and 'pear' are similar, because they are both 'eatable', have about the same 'weight', both 'grow on trees'.

`akin_to` : A concept is `akin_to` another concept if both concepts are connected using a path of `specialization_of` and `abstraction_of` relations. The relation has a parameter δ, the degree of kinship. The parameter describes the length of the path, which contains of `abstraction_of` and `specialization_of` relations.

Abstraction_of and specialization_of relations are itself special kinds of the akin_to relation, related by degree δ one. The corresponding set-valued function of the akin_to relation is called α.

$$\alpha(\delta) : C \Rightarrow \wp C$$

$$c_j \in \alpha(c_i, \delta) \Leftrightarrow (\exists path(c_i, ..., c_k, ..., c_j) of length \delta :$$
$$\forall c_k : (c_k \in \chi(c_{k+1})) \vee (c_k \in \sigma(c_{k+1}) \vee$$
$$((c_k \in \chi(c_{k+1})) \wedge (c_{k+1} \in \sigma(c_{k+2}));$$
$$c_k \neq c_{k+1} \neq c_{k+2}; i \neq j; i, j = 1, 2, ...; k = i, ..., j)$$

similar_to : A concept is similar to another concept, if both concepts have a set of attributes and values with respect to this attributes in common. The relation has a parameter δ, the Hamming distance (HD). The parameter describes the difference of both concepts with respect to their signatures (signature hamming distance SHD) and facts (fact hamming distance FHD). The corresponding set-valued function of the similar_to relation is called ζ

$$\zeta(\delta) : C \Rightarrow \wp C$$

$$\forall c_i, c_j : c_j \in \zeta(c_i, \delta)$$
$$\delta = \delta_\phi \vee \delta_\theta; i, j = 1, 2, ...$$

Signature Hamming distance SHD:

$$\delta_\phi = \left\|(\phi(c_i) \cup \phi(c_j)) - (\phi(c_i) \cap \phi(c_j))\right\|$$

Fact Hamming distance FHD:

$$\forall a_k \in (\phi(c_i) \cap \phi(c_j)) :$$

$$\delta_\theta = \left\|(\theta(c_i, a) \cup \theta(c_j, a)) - (\theta(c_i, a) \cap \theta(c_j, a))\right\|$$

4.2 BUILD-UP OF THE ONTOLOGY

In order to generate inspirational sentences that are related to a certain domain the ontology has to be filled with a lot of knowledge. The more knowledge the ontology contains, and the more dense this knowledge is connected, the more likely inspirational sentences will be generated. An ontology that contains knowledge from more than one domain can combine terms from different knowledge domains. Thus the users are invited to think across domain boundaries.

4.2.1 *Knowledge Elicitation*

There are two possibilities to elicit knowledge to add to the ontology: consulting external knowledge bases[4] and direct elicitation from the `stakeholders` of a problem. There are a lot of knowledge bases available, for example Wordnet[5] . For any given domain, most data for building up an ontology could probably be found here. This data needs to be converted to fit to the structure of the ontology. However, to detect the required relational information within complex lexical entries and to convert this to the correct relations in the ontology is not trivial. To create an automated transformation of data, like it occur in Wordnet, leads far from the main intention of this thesis. In the scope of the current thesis, I first aim at proving the feasibility of the approach as far as it concerns its use during IGSs. Only after it turns out to give significant contributions, effective approaches to knowledge elicitation can be a topic for further study. In order to be able to test the feasibility of the system in IGSs, knowledge is elicited directly from the user. Doing so gives the most control on consistency of the data entered into the ontology.

To elicit knowledge from the user is likewise not trivial, since there is no unique method for mapping it onto the ontology structure. In practice, it will require an experienced consultant to map knowledge from some domain. But in principle, this is doable for arbitrary domains.

4.2.2 *Complementing the Ontology*

Knowledge, given by the user, is usually fragmentary. The user gives statements like, "my shop has 10 employees, a secretary, two cleaners, five shop assistants and two warehouseman'. There are more information included than it is given explicitly in this sentence. Employees are people (human beings), men or women, they are payed for their job, every job contains different tasks and different working times. Several concepts, attributes and values have to be typed in and related to each other to represent these statements. Asking for all detailed information is a tedious task. It is very laborious to assure that all elements are related completely in terms of the ontology. It should suffice to type in the `fact`, a 'shop of garden facilities' (`concept`) has 'employees' (`attribute`), for example a 'secretary' (`value`). In particular, there are many trivial relations, such as `signatures` and `ranges` that can easily be deduced from given `facts`.

It is not intended to develop a system that is able to deal with domain knowledge in terms of learning, verifying, or deducing new knowledge. Therefore typed in knowledge statements are taken as propositions.

The knowledge in the ontology needs to be connected as densely as possible, but also typing in knowledge needs to be doable as fast and easy as possible. To support both, the ontology is complemented automatically by applying simple deduction rules on the relations in

4 A knowledge base is a special kind of database for knowledge management, it provides the means for the computerized collection, organization, and retrieval of knowledge[15]

5 Wordnet is a semantical lexicon for the English language[46][19]. English words are defined briefly in different senses and linked to each other. Wordnet contains 207,000 word sense pairs, and has a size of 12 megabytes[46]

the ontology. These deductions are syntactical, logical rules based on the semantics contained in the relations. Since the ontology has no mechanism to verify whether a relation is reasonable or meaningful, there is a risk in blindly applying deduction rules. To reduce the occurrence of many meaningless relations, only very simple and not too risky deductions will be used.

Knowledge Deduction

There are some trivial deductions that derive from the description of the ontology relations. A concept and an attribute that are related by `signature`, are related by `domain`, too. Similarly, `abstraction_of` relates two concepts and `specialization_of` relates the same concepts in reverse order. A `fact` relates a concept with its describing attributes and assigned values, therefore it includes a `signature` relation and also a `range` relation. For example, from the `fact` 'the color of a car is red', it can be deduced that the 'color' is in the `signature` of 'car' and 'red' is in the `range` of 'color'. The other way around, the signature relation between a concept and an attribute and the range relation between this attribute and a value generates a correct fact. But using this deduction rather unspecific facts would be generated. Also, the definition of the `opposite_of` relation leads to a trivial deduction.

- For every domain relation of an attribute and a concept there is also a signature relation between this concept and this attribute, and vice versa. (rule 1)

$$\forall c, a : c \in C, a \in A : c \in \psi(a) \Leftrightarrow a \in \phi(c)$$

- For every `abstraction_of` relation of a concept c_j and another concept c_i there is also a `specialization_of` relation between concept c_i and concept c_j, and vice versa. (rule 2)

$$\forall c_i, c_j : c_i, c_j \in C : c_i \in \sigma(c_j) \Leftrightarrow c_j \in \chi(c_i)$$

- For every `fact` relation, the attribute is part of the `signature` of the `fact`'s concept, and the value is part of the `range` of the `fact`'s attribute. (rule 3)

$$\forall c, a, v : c \in C, a \in A, v \in V : v \in \theta(c, a) \Rightarrow a \in \phi(c) \land v \in \rho(a)$$

- For every `range` of an attribute a that contains one value v_i that occurs in an `opposite_of` relation with another value v_j, this range also contains the other value. (rule 4)

$$\forall v_i, v_j, c : v_i, v_j \in V, a \in A : v_i \in \rho(a) \land v_j = \omega(v_i, a) \Rightarrow v_j \in \rho(a)$$

There are further automatic deductions. Consider the following example. A 'car' moves on the 'medium' 'ground', so 'ground' is a value in the `range` of 'medium'. 'Ground' can also occur as concept in the ontology, related to the value 'ground' by the `value_is_concept` relation. Since 'ground' is a possible 'medium', and 'permafrost ground' is a `specialization_of` the concept 'ground', also the value 'permafrost ground' is in the range of 'medium'. So specializations of concepts, which occur as values in a specific range, can be values in the same range too.

- For every `range` relation of an attribute a and a value v_j, where the value v_j occurs as a concept c_j, and this concept c_j is an `abstraction_of` another concept c_i, concept c_i occurs also as a value v_i of the same range. (rule 5)

$$\forall c_i, c_j, v_i, v_j, a : c_i, c_j \in C, v_i, v_j \in V, a \in A :$$

$$v_j \in \rho(a) \wedge v_j \in \mu(c_j) \wedge c_j \in \chi(c_i)$$
$$\Rightarrow \exists v_i : v_i \in \mu(c_i) \wedge v_i \in \rho(a))$$

Also within the `lattice` of concepts it is possible to deduce relations for complementing the ontology. For example, from the relation 'a man' is a special kind of 'human being' and a 'human being' is a special kind of 'living being' is deduced 'a man' is a special kind of 'living being'. By creating the transitive closure according to the `specialization_of` relation, the hierarchy of concepts is flattened. Such a flat hierarchy of concepts provides finding shortcuts between concepts that are relatives of each other.

- If there is a concept c_i that is a `specialization_of` another concept c_j, and concept c_j is also a `specialization_of` concept c_k, concept c_i is also a `specialization_of` concept c_k. (rule 6)

$$\forall c_i, c_j, c_k : c_i, c_j, c_k \in C : c_i \in \sigma(c_j) \wedge c_j \in \sigma(c_k) \Rightarrow c_i \in \sigma(c_k)$$

Also, it is possible to deduce `specialization_of` relations from structural information contained in the ontology. For instance, a 'stool' that is specified by 'contains of rigid materials and is intended to sit on' becomes a special kind of 'chair', if the chair is also an object that is used to sit on that also is required to be rigid and possible to sit on.

- For any two concepts c_i and c_j, where the `signature` of concept c_i contains the `signature` of concept c_j and all `fact` relations of c_i are contained in the `facts` of c_j regarding attributes of the `signature` of c_j, concept c_i is a `specialization_of` concept c_j. (rule 7)

$$\forall c_i, c_j, a : c_i, c_j \in C, a \in A :$$

$$\phi(c_i) \supseteq \phi(c_j) \wedge (\forall a \in \phi(c_j) : \theta(c_i, a) \subseteq \theta(c_j, a))$$
$$\Rightarrow c_i \in \sigma(c_j)$$

Deduction rule 7 is correct, but it might generate inconsistencies of the represented knowledge with respect to intuition. For instance, if a 'ball' is defined as 'red and spherical' and a 'tomato' is specified as 'eatable, red and spherical' this deduction would make a 'tomato' a `specialization_of` 'ball', which is correct, if there is no more information about balls or tomatoes. But this relation is contrary to intuition. Mild forms of inconsistencies can be useful for the purpose to inspire idea generation, but too extreme inconsistencies might create relations that will be interpreted as being nonsense. To avoid generating nonsense sentences, this deduction is refused.

There are further deductions based on inheritance and classification. For instance, a ’car’ has the signature ’color’, ’owner’, ’speed’, ’actuation’, ’engine displacement’. A ’Toyota’ is defined as a as a special kind of ’car’, so the ’Toyota’ inherits the signature of the ’car’.

Also, facts of the abstract concept can be inherited to the specialized concepts, for example, the purpose of a car is to ’transport people and luggage’. The same purpose can be assumed to all specialized cars. An inheritance of properties the other way around is also possible. If the ’Toyota’ is specified by the ’brand Toyota’, and all other specialized cars are also of a specific ’brand’, ’brand’ becomes an additional attribute of the `signature` of ’car’. The deduced relations have to be checked again after any attribute from the signatures of the specialized concepts is removed.

- For every `signature` relation of a concept c_i that occurs in a `specialization_of` another concept c_j, c_i inherits the signature from the abstract concept c_j. (rule 8)

$$\forall c_i, c_j, a : c_i, c_j \in C, a \in A :$$

$$\forall c_i : c_i \in \sigma(c_j) \wedge (\forall a : a \in \phi(c_j)) \Rightarrow a \in \phi(c_i)$$

- For every `fact` relation of a concept c_i that occurs in a *specialization_of* another concept c_j, c_i inherits the `fact` from the abstract concept c_j. (rule 9)

$$\forall c_i, c_j, a, v : c_i, c_j \in C, a \in A, v \in V :$$

$$\forall c_i : c_i \in \sigma(c_j) \wedge (\forall a : a \in \phi(c_j) \wedge (\forall v : v \in \theta(c_j, a))) \Rightarrow v \in \theta(c_i, a)$$

- For all `signature` relations that all specialized concepts c_i of a concept c_j have in common, the attribute is also in the `signature` of the abstract concept. (rule 10)

$$\forall c_i, c_j, a : c_i, c_j \in C, a \in A :$$

$$\forall c_j : (\forall a : (\forall c_i : c_i \in \sigma(c_j) : a \in \phi(c_i)) \Rightarrow a \in \phi(c_j))$$

When defining the `specialization_of` relation, it was stated that the specialized concept has a subset of `facts` of the abstract concept, with respect to all attributes that both have in common. Deduction rule 9 corrupts this definition, therefore it cannot be applied.

The definition of the `specialization_of` relation gives rise to another deduction: All facts of a specialized concept, regarding an attribute of the signature of a concept that is an abstraction to the first concept, can be propagated to the abstract concept (rule 11). For instance, a ’passenger car moves in the medium ground’, similar as a ’bus’. A ’ferry boat moves in the medium water’. A ’passenger plane’ moves in the medium air’. A ’passenger car’ and a ’bus’ are both specializations of the concept ’car’. Similarly, a ’ferry boat’ is a ’boat’, and a ’passenger plane’ a special kind of ’plane’. A ’hovercraft’ moves on ’ground’ and ’water’, and therefore, it is both, a ’car’ and a ’boat’. By definition of `specialization_of`, ’boat’ and ’car’ get both media: ’water’ and 'ground'. Now, the concept 'bat mobile'[6] is added, which is a very special kind of 'car' that is able to fly. The 'bat mobile' is both, a 'car' and a 'plane'. By applying the current deduction, the 'media' of car are extended to 'water', 'ground' and 'air', similarly the 'media' of 'plane' and 'boat' assume this values. The sub lattice containing this example is shown in figure 3. This deduction produces all possible facts in an abstract concept that occur with any of the abstract concepts specializations. So, this deduction produces very unspecific concept descriptions, because the most abstract concepts will contain a large amount of facts that are irrelevant for this concept.

- For all `fact` relations of all specialized concepts c_i of a concept c_j, where the attribute a is in the `signature` of the abstract concept c_j, the value v is also in the `facts` of c_j. (rule 11)

$$\forall c_i, c_j, a, v : c_i, c_j \in C, a \in A, v \in V :$$

$$\forall c_j : c_j \in C, \forall v : v \in V, \forall a : a \in \phi(c_j) :$$
$$(\forall c_i : c_i \in \sigma(c_j), a \in \phi(c_i) : v \in \theta(c_i, a)) \Rightarrow v \in \theta(c_j, a)$$

Alternatively, only the facts that all specialized concepts have in common could be propagated to the abstract concept. By this alternative deduction, the ontology would contain much less information. Using the example above, a 'car' would not have a specified value for 'medium', since none of the possible values is in common in all specializations of 'car'. Applying this deduction to the example above, will create a sub lattice as shown in figure 4.

- For all `fact` relations of all specialized concepts c_i of a concept c_j, where the attribute a is in the `signature` of the abstract concept c_j, and the value v is in common with all other specialized concepts of c_j, v is also in the `facts` of c_j. (rule 12)

$$\forall c_j : c_j \in C, \forall a : a \in \phi(c_j) :$$
$$(\forall v : v \in V : (\forall c_i : c_i \in \sigma(c_j), a \in \phi(c_i) \wedge v \in \theta(c_i, a)) \Rightarrow v \in \theta(c_j, a))$$

Deduction rule 11 provides all possible values of facts for abstract concepts; deduction rule 12 provides all necessary values of facts. Since the Kalliope approach is intended to help people to think about possibilities, not about necessities, rule 11 is preferable.

All deduction rules, except for rules 7, 9, and 12, are applied to complement the ontology.

4.3 SYNTHESIS OF INSPIRATIONAL SENTENCES

The ontology is required to synthesize sentences that are sufficiently precise and in some sense meaningful in relation to the problem domain. In this section it is be described how the ontology can be used to synthesize such precise and meaningful sentences.

6 A bat mobile is the vehicle that is used by the comic hero Batman. It is a kind of car that has wings to fly, too.

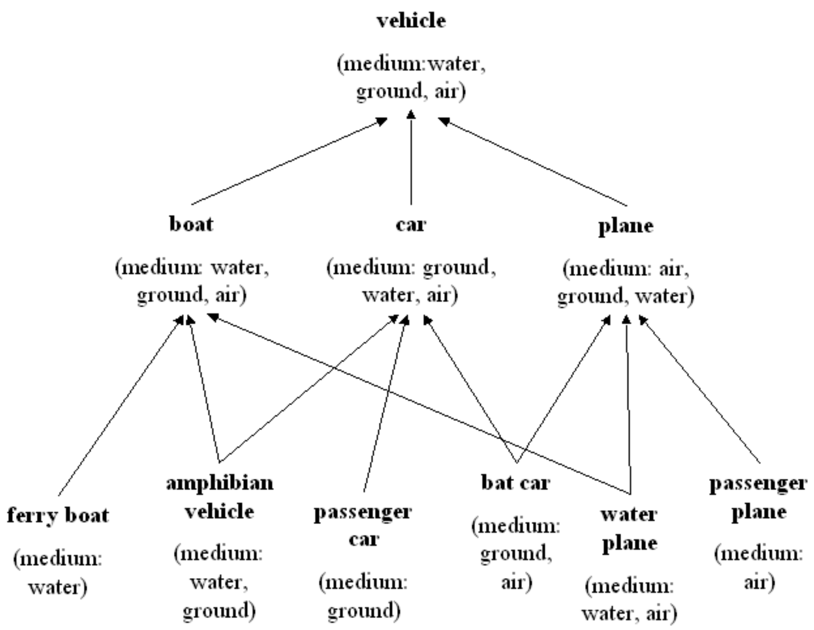

Figure 3. Example application of deduction rule 11: the union of facts of specialized concepts, regarding attributes of the abstract concept's signature, is propagated to the abstract concept.

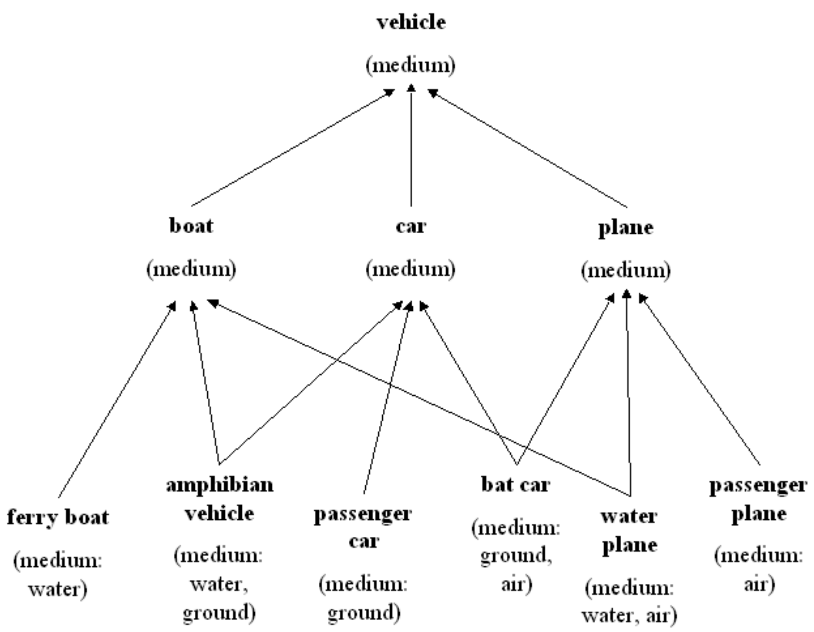

Figure 4. Example application of deduction rule 12: the intersection of facts of specialized concepts, regarding attributes of the abstract concept's signature, is propagated to the abstract concept.

4.3.1 *Generation of Inspirational Combinations*

To synthesize inspirational sentences, the main principles of inspirational sentences (see section 3.1.3) have to be implemented:

SCRUTINIZING : scrutinize existing knowledge, for instance, ask if some given or deduced `fact` necessarily must be true.

SUBSTITUTIONS : recombine existing knowledge in the ontology, for instance, substitute the value and/or attribute of an existing `fact` or `signature` relation by an alternative value and/or attribute.

ASSOCIATION : associate different concepts to provide searching for analogies between both concepts.

To perform this restructuring operations, existing relation tuples[7] or single elements are taken and modified (negated, recombined, associated). `Focusing` on aspects of the domain is realized by navigating in the ontology via existing relations and applying the other three restructuring operations on certain concepts in the ontology.

Scrutinizing Knowledge

The `problem owner` and `stakeholders` often take knowledge of the domain for granted. It may give a refreshing new view onto the problem if one admits the idea that something could be different from what it always has been. This phenomenon is called 'restructuring' by psychologists, 'change of perspective' by Idea Engineering. This principle occurs in 'inversion' methods of creativity techniques and also in suggestions, like: *Imagine your shop of garden facilities would not sell things*.

Scrutinizing existing knowledge can be implemented by adding a 'NOT' to particular relations in the ontology. For instance, in the suggestion example above, the fact ('shop of garden facilities', 'sell', 'things') is scrutinized. This suggestion allows two interpretations. First, the shop of garden facilities could not be a usual business, making money by selling things (things here is meant general for products, tools, services etc.). The shop could buy things instead of selling things (selling and buying are inverse activities), or lend or rent tools or train people using tools. Second, the shop of garden facilities could sell something else than the usual, material objects. for example, it could sell animals, services or maintenance.

In `fact` relations, it is either possible to challenge the attribute or to challenge the value. The fact tuple ('shop of garden facilities', 'sell', 'things') can be scrutinized in two ways: first, scrutinizing the attribute 'sell' generates a tuple ('shop of garden facilities', NOT + 'sell', 'things'; second, scrutinizing the value generates a tuple ('shop of garden facilities', 'sell', NOT + 'things'). This can be rephrased to 'alternative things' or 'non-objects'. So, scrutinizing fact relations is applied using the following strategies:

- Scrutinize the `attribute` of a `fact`. (strategy 1)

$$(c, a, v) : v \in \theta(c, a) \Longrightarrow (c, \mathrm{NOT} + a, v)$$

7 A tuple is a finite sequence of objects, each of a specified type[18].

- Scrutinize the `value` of a `fact`. (strategy 2)

$$(c, a, v) : v \in \theta(c, a) \Longrightarrow (c, a, \mathrm{NOT} + v)$$

Also `signature` relations can be challenged. For example, the attribute 'has shop assistants' of the signature relation ('shop of garden facilities', 'has shop assistants') can be scrutinized: ('shop of garden facilities', NOT + 'has shop assistants'). This leads to the question, if a shop has no shop assistants, how can selling be organized then?

- Scrutinize the `attribute` of a `signature` relation. (strategy 3)

$$(c, a) : a \in \phi(c) \Longrightarrow (c, \mathrm{NOT} + a)$$

The `specialization_of` relation can be challenged, too. A concept that occurs as a specialization of another concept could not be a kind of this abstract concept, which means it would not have the properties of this abstract concept. For instance, if the specialization_of relation ('shop of garden facilities', 'building') could be negated. If a 'shop of garden facilities' would not be a 'building' that has a static location, it would be free to move. 'Driving libraries' are an example for a service, namely a 'library', which is usually located in a static 'building', but in this case, the service is located in a movable 'bus'.

- Scrutinize a `concept` being a `specialization_of` another `concept`. (strategy 4)

$$(c_i, c_j) : c_i \in \sigma(c_j) \Longrightarrow (c_i, \mathrm{NOT} + c_j)$$

Scrutinizing a `fact` or `signature` relation of a concept aims at inviting the user to rethink properties of the concept. Scrutinizing the `specialization_of` relation of a concept to another, more abstract concept aims at inviting the user to rethink general, inherited properties of this concept, and to search for alternatives.

Associating Knowledge

To associate different concepts is a common method used in creativity techniques. By associating concepts, two concepts that may differ significantly can be pulled together. This can change the view according to the concept and maybe the problem, too. To associate a 'car' with a 'frog' might be weired, but it can lead to unusual ideas, like 'hopping cars' or 'amphibian cars'.

Two concepts can be associated that are either arbitrary, or similar, or different to each other. To associate a concept to one of its abstractions is not very helpful. The suggestion, imagine a 'Toyota' is a 'car', is not inspirational for getting a new ideas. The similarity of two concepts can be calculated using the Hamming distance, as described in section 4.1.2. If the HD between two concepts is within a particular threshold Δ, both concepts are defined as similar, otherwise both concepts are different. The following strategies for finding concepts for associating are developed:

- Associate a concept to an arbitrary concept. (strategy 5)

$$c \implies (c, c_a) : (c_a \notin \chi(c)) \wedge (c_a \neq c)$$

- Associate a concept to a similar concept. Both concepts must have a Hamming distance smaller than a specific threshold Δ. (strategy 6)

$$c \implies (c, c_a) : (c_a \notin \chi(c)) \wedge (c_a \neq c) \wedge$$
$$c_a : c_a \in C, c_a \in \zeta(c, \delta); \delta \leqslant \Delta$$

- Associate a concept to a different concept. Both concepts have to be related by the `similar_to` relation with a Hamming distance bigger than a specific threshold Δ. (strategy 7)

$$c \implies (c, c_a) : (c_a \notin \chi(c)) \wedge (c_a \neq c) \wedge$$
$$c_a : c_a \in C, c_a \in \zeta(c, \delta); \delta > \Delta$$

Recombining Knowledge

The strongest strategy for inspirational questions consists of meaningful substitution of elements in relations in the ontology. To 'locate' the 'shop of garden facilities' in the 'desert' instead of the 'city center', or to have 'handicapped people' instead of 'people' as 'customers' is very likely to inspire people to have unusual ideas. To synthesize such inspirational, meaningful suggestions is not trivial, because it requires a lot of precise knowledge. Nevertheless, I am intrigued by the idea to synthesize inspirational sentences with precisely this recombinations-type quality.

There are two relations that can be recombined meaningfully, namely `signature` and `fact` relations.

`Signature` relations can be recombined by replacing an attribute of a concept's `signature` with an alternative attribute that does not occur in the concept's `signature`. So, unusual aspects and properties can be imagined. For example, a 'car' could have 'wings' or 'vats', or a 'shop of garden facilities' could have a 'gallery'. There are several options of alternative attributes to recombine a `signature`:

- Replace the attribute of a concept's `signature` with an arbitrary attribute a_s that is not in the `signature` of this concept. (strategy 8)

$$(c, a) : a \in \phi(c) \implies (c, a_s) : (a_s \notin \phi(c)) \wedge (a_s \neq a)$$

- Replace the attribute of a concept's `signature` with an attribute a_s of the `signature` of a concept c_s that is `akin_to` the first concept. (strategy 9)

$$(c, a) : a \in \phi(c) \implies (c, a_s) : (a_s \notin \phi(c)) \wedge (a_s \neq a) \wedge$$
$$a_s : (\exists c_s : c_s \in \alpha(c, \delta) : a_s \in \phi(c_s))$$

- Replace the attribute of a concept's signature with an attribute a_s of the signature of a concept c_s that is a specialization_of the first concept. (strategy 10)

$$(c, a) : a \in \phi(c) \Longrightarrow (c, a_s) : (a_s \notin \phi(c)) \wedge (a_s \neq a) \wedge$$

$$a_s : (\exists c_s : c_s \in \sigma(c) : a_s \in \phi(c_s))$$

- Replace the attribute of a concept's signature with an attribute a_s of the signature of a concept c_s that is similar_to the first concept. Both concepts are related by similar_to with a Hamming distance lower than an allowed threshold. (strategy 11)

$$(c, a) : a \in \phi(c) \Longrightarrow (c, a_s) : (a_s \notin \phi(c)) \wedge (a_s \neq a) \wedge$$

$$a_s : (\exists c_s : c_s \in \zeta(c, \delta), \delta \leqslant \Delta : a_s \in \phi(c_s))$$

- Replace the attribute of a concept's signature with an attribute a_s of the signature of a concept c_s that is different to the first concept. Both concepts are related by similar_to with a Hamming distance higher than an allowed threshold. (strategy 12)

$$(c, a) : a \in \phi(c) \Longrightarrow (c, a_s) : (a_s \notin \phi(c)) \wedge (a_s \neq a) \wedge$$

$$a_s : (\exists c_s : c_s \in \zeta(c, \delta), \delta > \Delta : a_s \in \phi(c_s))$$

In facts, either the value or both, the attribute and the value, can be substituted. Recombining facts aims at inviting the user to think about details of the problem. Consider the fact ('shop of garden facilities','sale','tools for gardening'). The attribute 'sale' could be replaced, for instance, with an attribute 'maintenance', and simultaneously the value 'tools for gardening' could be replaced with a value 'garden ponds'. Another option is to replace only the value of the 'fact', for instance, by other things that can be sold, for example 'pets' or 'clothes'.

There are several strategies to substitute values of facts. The alternative values always have to be within the same range as the original value. For instance, to replace the color 'red' with a 'number' would create nonsense. Values can be replaced with opposite or arbitrary values. For instance, the 'position of the driver' in a 'car' could be 'back' instead of 'front' (opposite value), or a 'car' could have the 'color' 'blue' instead of 'red' (arbitrary value from the same range). More interesting combinations are generated by replacing values that occur as concepts with values of concepts that are specialized, similar, different or akin to the original concept. For instance, the fact the 'customers' of a 'shop of garden facilities' are 'people' can be recombined to the suggestion: the 'customers' of a 'shop of garden facilities' are 'children' or 'handicapped people'. Alternative values can be found by the following strategies:

- Replace the value of a concept's fact regarding an attribute a with an arbitrary value that is in the same range. (strategy 13)

$$(c, a, v) : v \in \theta(c, a) \Longrightarrow (c, a, v_s) : v_s \notin \theta(c, a) \wedge v_s \in \rho(a)$$

- Replace the value of a concept's `fact` regarding an attribute a with a value that is `opposite` to the first value regarding the attribute a. (strategy 14)

$$(c, a, v) : v \in \theta(c, a) \Longrightarrow (c, a, v_s) : v_s \notin \theta(c, a) \wedge v_s \in \rho(a) \wedge$$

$$v_s : v_s \in \omega(v, a)$$

- Replace the value v of a `fact` that occurs as a concept c_v with the value v_s of a concept c_s, which is a `specialization_of` concept c_v. (strategy 16)

$$(c, a, v) : v \in \theta(c, a) \Longrightarrow (c, a, v_s) : v_s \notin \theta(c, a) \wedge v_s \in \rho(a) \wedge$$

$$v_s : (\exists c_v : c_v = \mu(v), \exists c_s : c_s \in \sigma(c_v), v_s = \mu^{-1}(c_s))$$

Some more adventurous substitutions can be very inspirational, for example, replacing the value 'people' with 'animals'. To find the alternative values 'children' or 'handicapped people', which are special kinds of 'people' is only one step in the lattice of concepts. But to find the concept 'animals' requires to search a few steps in the lattice via `abstraction_of` and `specialization_of` relations. These steps are determined by the parameter degree of kinship of the `akin_to` relation. In this example, 'people' are specializations of 'living beings' and 'animals' are another specialization. The number of steps for a helpful inspiration is not known in beforehand. This depends on the imaginative skills of the people who should react on the inspirational suggestions.

- Replace the value v of a `fact` that occurs as a concept c_v with the value v_s of a concept c_s, which is `akin_to` concept c_v. (strategy 15)

$$(c, a, v) : v \in \theta(c, a) \Longrightarrow (c, a, v_s) : v_s \notin \theta(c, a) \wedge v_s \in \rho(a) \wedge$$

$$v_s : (\exists c_v : c_v = \mu(v), \exists c_s : c_s \in \alpha(c_v, \delta), v_s = \mu^{-1}(c_s))$$

- Replace the value v of a `fact` that occurs as a concept c_v with the value v_s of a concept c_s, which is `similar_to` concept c_v. The HD between the substituted concepts must be smaller than a specific threshold Δ. (strategy 17)

$$(c, a, v) : v \in \theta(c, a) \Longrightarrow (c, a, v_s) : v_s \notin \theta(c, a) \wedge v_s \in \rho(a) \wedge$$

$$v_s : (\exists c_v : c_v = \mu(v), \exists c_s : c_s \in \zeta(c_v, \delta), \delta \leqslant \Delta, v_s = \mu^{-1}(c_s))$$

- Replace the value v of a `fact` that occurs as a concept c_v with the value v_s of a concept c_s, which is `similar_to` concept c_v. The HD between the substituted concepts must be smaller than a specific threshold Δ. (strategy 17)

$$(c, a, v) : v \in \theta(c, a) \Longrightarrow (c, a, v_s) : v_s \notin \theta(c, a) \wedge v_s \in \rho(a) \wedge$$

$$v_s : (\exists c_v : c_v = \mu(v), \exists c_s : c_s \in \zeta(c_v, \delta), \delta \leqslant \Delta, v_s = \mu^{-1}(c_s))$$

- Replace the value v of a `fact` that occurs as a concept c_v with the value v_s of a concept c_s, which is different to concept c_v. The HD between the substituted concepts must be bigger than a specific threshold Δ. (strategy 18)

$$(c, a, v) : v \in \theta(c, a) \Longrightarrow (c, a, v_s) : v_s \notin \theta(c, a) \wedge v_s \in \rho(a) \wedge$$
$$v_s : (\exists c_v : c_v = \mu(v), \exists c_s : c_s \in \zeta(c_v, \delta), \delta > \Delta, v_s = \mu^{-1}(c_s))$$

- Replace the value v of a concept's `fact` with an attribute a with the value v_s of another concept's `fact` with the same attribute a. (strategy 19)

$$(c, a, v) : v \in \theta(c, a) \Longrightarrow (c, a, v_s) : v_s \notin \theta(c, a) \wedge v_s \in \rho(a) \wedge$$
$$v_s : (\exists c_s : c_s \in C : v_s \in \theta(c_s, a))$$

- Replace the value v of a concept's `fact` with an attribute a with the value v_s of a concept's fact, with the same attribute a that is `akin_to` the first concept. (strategy 20)

$$(c, a, v) : v \in \theta(c, a) \Longrightarrow (c, a, v_s) : v_s \notin \theta(c, a) \wedge v_s \in \rho(a) \wedge$$
$$v_s : (\exists c_s : c_s \in \alpha(c, \delta) : v_s \in \theta(c_s, a))$$

- Replace the value v of a concept's `fact` with an attribute a with the value v_s of a concept's fact, with the same attribute a that is a `specialization_of` the first concept. (strategy 21)

$$(c, a, v) : v \in \theta(c, a) \Longrightarrow (c, a, v_s) : v_s \notin \theta(c, a) \wedge v_s \in \rho(a) \wedge$$
$$v_s : (\exists c_s : c_s \in \sigma(c) : v_s \in \theta(c_s, a))$$

- Replace the value v of a concept's `fact` with an attribute a with the value v_s of a concept's fact, with the same attribute a that is `similar_to` the first concept (with a HD smaller than the threshold Δ). (strategy 22)

$$(c, a, v) : v \in \theta(c, a) \Longrightarrow (c, a, v_s) : v_s \notin \theta(c, a) \wedge v_s \in \rho(a) \wedge$$
$$v_s : (\exists c_s : c_s \in \zeta(c, \delta), \delta \leqslant \Delta : v_s \in \theta(c_s, a))$$

- Replace the value v of a concept's `fact` with an attribute a with the value v_s of a concept's fact, with the same attribute a that is different to the first concept (with a HD bigger than the threshold Δ). (strategy 23)

$$(c, a, v) : v \in \theta(c, a) \Longrightarrow (c, a, v_s) : v_s \notin \theta(c, a) \wedge v_s \in \rho(a) \wedge$$
$$16) v_s : (\exists c_s different : c_s \in \zeta(c, \delta), \delta > \Delta : v_s \in \theta(c_s, a))$$

Replacing attributes and values of facts aims at modifying the knowledge about a concept drastically. Consider a 'shop of garden facilities' is combined with the attribute 'actuation' and value 'engine'. Such interesting alternative attributes and values have to be taken from the facts of another concept. This concept can be arbitrary, but also akin, specialized, similar or very different. Meaningful recombinations of facts with alternative attributes and values can be generated by the following strategies:

- Replace the attribute and the value of a concept's `fact` with the attribute and the value of the `fact` of another, arbitrary concept, which occur not in `facts` of the first concept. (strategy 24)

$$(c, a, v) : v \in \theta(c, a) \Longrightarrow (c, a_s, v_s) : v_s \notin \theta(c, a) \wedge a_s \notin \phi(c) \wedge v_s \in \rho(a_s) \wedge$$
$$a_s, v_s : (\exists c_s : c_s \in C : v_s \in \theta(c_s, a_s))$$

- Replace the attribute and the value of a concept's `fact` with the attribute and value of the `fact` of another concept that is `akin_to` the first concept. (strategy 25)

$$(c, a, v) : v \in \theta(c, a) \Longrightarrow (c, a_s, v_s) : v_s \notin \theta(c, a) \wedge a_s \notin \phi(c) \wedge v_s \in \rho(a_s) \wedge$$
$$a_s, v_s : (\exists c_s : c_s \in \alpha(c, \delta) : v_s \in \theta(c_s, a_s))$$

- Replace the attribute and the value of a concept's `fact` with the attribute and value of the `fact` of another concept that is a `specialization_of` the first concept. (strategy 26)

$$(c, a, v) : v \in \theta(c, a) \Longrightarrow (c, a_s, v_s) : v_s \notin \theta(c, a) \wedge a_s \notin \phi(c) \wedge v_s \in \rho(a_s) \wedge$$
$$a_s, v_s : (\exists c_s : c_s \in \sigma(c) : v_s \in \theta(c_s, a_s))$$

- Replace the attribute and the value of a concept's `fact` with the attribute and value of the `fact` of another concept that is `similar_to` the first concept. (strategy 27)

$$(c, a, v) : v \in \theta(c, a) \Longrightarrow (c, a_s, v_s) : v_s \notin \theta(c, a) \wedge a_s \notin \phi(c) \wedge v_s \in \rho(a_s) \wedge$$
$$a_s, v_s : (\exists c_s : c_s \in \zeta(c, \delta), \delta \leqslant \Delta : v_s \in \theta(c_s, a_s))$$

- Replace the attribute and the value of a concept's `fact` with the attribute and value of the `fact` of another concept that is different to the first concept. (strategy 28)

$$(c, a, v) : v \in \theta(c, a) \Longrightarrow (c, a_s, v_s) : v_s \notin \theta(c, a) \wedge a_s \notin \phi(c) \wedge v_s \in \rho(a_s) \wedge$$
$$a_s, v_s : (\exists c_s : c_s \in \zeta(c, \delta), \delta > \Delta : v_s \in \theta(c_s, a_s))$$

In sum 28 different inspiration strategies are developed. Every strategy modifies an existing relation or creates an new one. The principles scrutinizing and recombination are applied to specific initial relations. Every strategy modifies one or more elements of this relation. Scrutinizing simply adds a 'not'; in recombinations the elements are replaced with alternative elements. These alternative elements are found using relation paths in the ontology. The principle of association is only applied to concepts. Also in this strategy the alternative concept is found using relations in the ontology.

Since all relations use only existing elements and relations in the ontology, they produce precise combinations of ontology elements.

4.3.2 *Search for Inspirational Combinations*

Once the ontology is wide (that is, an ontology with many different concepts, attributes and values) and densely connected (that is, the collection of relations is relatively large), there is a large chance that unusual, but potentially interesting new combinations occur. Such new combination may connect various domains. But then, it is easily possible to lose the way in the ontology and calculate irrelevant suggestions according to the current problem.

There are two options in which order inspirational strategies can be applied, either as a random sequence or a structured one. A random sequence has the advantage to explore a large subset of the ontology. But it also has the disadvantage of being too random so that it fails to support people's thinking. Therefore, it is helpful to choose a number of concepts that specify the most important concepts that are related to the problem. These concepts are called `control points`. The control points serve to navigate in the ontology and to search for concepts (and relations of these concepts) that will be modified by the inspiration strategies. A control point should not dominate the process too long. Therefore, a new control point should be chosen after a certain amount of time.

Nevertheless, it is possible to drift too far from the problem. To assure that every of the selected concepts is sufficiently near related to a control point, the distance between this concept and the control point should be limited. This distance is called `problem distance`. It describes the length of the path between two concepts via `fact` plus `value_is_concept` relations in the ontology. Consider again the example problem *to extend the service of a shop of garden facilities*. The concept 'shop of garden facilities' is chosen as a control point. This concept has a fact: the 'shop of garden facilities' 'sells' 'tools for gardening'. The value 'tools for gardening' occurs also as a concept (there is a value_is_concept relation between the value and the concept). This concept has a fact: 'tools for gardening' are 'used for' 'gardening'. The value 'gardening' occurs also as a concept. Inspirational sentences regarding the concept 'gardening' might inspire a user to generate ideas that serves to find an new service of the shop of garden facilities. In this example the problem distance is two. The principle of using control points and the problem distance to search for concepts that are modified by inspiration strategies is shown in figure 5.

For some problem very weird suggestions are welcomed, for others more serious ones may be expected. The weirdness cannot always be defined in advance, it depends on the problem and mainly the problem owner, and also participants of the IGS. The weirdness of suggestions can be controlled by parameterizing the HD, and similarly the number of jumps in the lattice, which in turn determines the degree of kinship between akin concepts. These parameters can be set prior to an IGS and also adapted underway.

Not all strategies might be equally adequate for any problem. Hence the strategies can be weighted that is: the probability for a certain strategy to be chosen by the system may vary from one strategy to another. These weights can be adapted, for instance, regarding the usefulness of the strategy for a certain problem, or according to intermediate

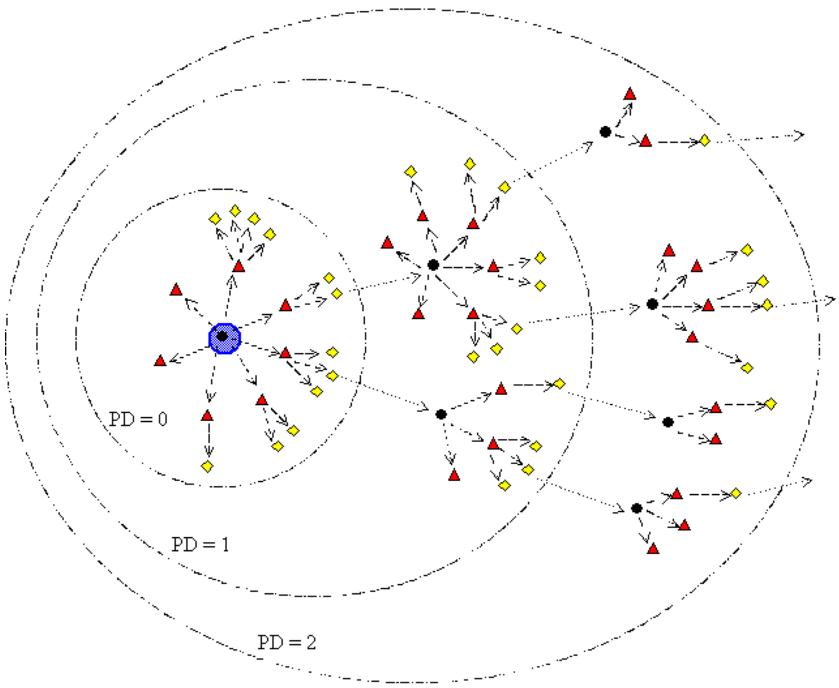

Figure 5. Navigation in the ontology: using a predefined `control point` (blue circle) and a specified `problem distance` (PD), a subset of the ontology is admitted as domain for navigation. The inspiration strategies are applied to elements and relations within this subset only, to assure the inspirational sentences are sufficiently related to the problem to solve. But searching for alternative elements is not limited to this subset, the strategies take into account the whole ontology.

feedback of the participants of the IGS.

These alternatives of adapting the weight of the strategy lead to two modi for generating inspirational sentences: offline and online calculation. For long calculation processes batch processing is more efficient. This does not allow intervening with control points, and other parameters during an IGS, however. Therefore the online option is preferred, where inspirational sentences are calculated on request during the session. It is difficult to predict response times, but I consider waiting for less than a minute acceptable.

4.3.3 *Postprocessing of Inspirational Combinations*

By means of the inspiration strategies, inspirational combinations are generated. These combinations have to be processed to create understandable sentences. To use simple sentence patterns that contain of a subject, predicate and object (SPO) only is one option. One SPO is used for each restructuring type.

- Scrutinize a `fact` relation: 'Imagine' <attribute> 'of' <concept> 'would not be' <value> '.';
- Scrutinize a `signature` relation: 'Imagine' <concept> 'would not have' <attribute> '.';
- Scrutinize a `specialization_of` relation: 'Imagine' <concept> 'would not be' <abstract concept> '.';
- Associate two concepts: 'Imagine' <concept> 'would be' <associated concept> '.';
- Substitute the value of a `fact` relation: 'Imagine' <attribute> 'of' <concept> 'would be' <substituted value> '.';
- Substitute the attribute and the value of a `fact` relation: 'Imagine' <concept> 'would have' <substituted attribute> 'being' <substituted value> '.';
- Substitute the attribute of a `signature` relation: 'Imagine' <concept> 'would have' <substituted attribute> '.'.

This sentence patterns can be expressed in terms of a grammar, using the following production rules:
<inspiration> ::=
<scrutinizing> | <association> | <recombination>
<scrutinizing> ::=
<fact scrutinizing> | <signature scrutinizing> | <lattice scrutinizing>
<fact scrutinizing> ::=
'Imagine' <attribute> 'of' <concept> 'would not be' <value> '.'
<signature scrutinizing> ::=
'Imagine' <concept> 'would not have' <attribute> '.'
<lattice scrutinizing> ::=
'Imagine' <concept> 'would not be' <abstract concept> '.'
<association> ::=
'Imagine' <concept> 'would be' <associated concept> '.'

<recombination> ::=
<fact v recombination> | <fact av recombination> | <signature recombination>
<fact v recombination> ::=
'Imagine' <attribute> 'of' <concept> 'would be'
<substituted value> '.'
<fact av recombination> ::=
<concept> 'would have' <substituted attribute> 'being' <substituted value> '.'
<signature recombination> ::=
<concept> 'would have' <substituted attribute> '.'

The sentences produced by this grammar are not always grammatically correct, since grammatical case, gender information and declination are not taken into account. Some of the grammatically relevant information could be stored in the ontology, as additional information of each element, for example information of the word type. But adapting the elements according to declination, gender and other grammatical issues needs a more complex postprocessing procedure. To develop such postprocessing machinery that builds grammatically correct sentences, is not trivial (see [24]). The main focus in this thesis is to develop an approach to support idea generation by restructuring knowledge. If the evaluation of the prototype shows that this approach is promising, a more complex postprocessing procedure can be developed.

4.4 CHAPTER SUMMARY

In this chapter the ontology-based approach for supporting idea generation was explained in detail. The ontology structure was determined, and also methods to complement this ontology were discussed. Furthermore, it was explained how the ontology can be used to generate combinations of ontology elements, which are assumed to be inspirational. A set of heuristic strategies is developed to restructure the knowledge stored in the ontology. These strategies imitate thinking strategies of a human interviewer who aims at scrutinizing a problem and inspiring idea generation. Some examples of inspirational sentences generated by means of the inspiration strategies will be given after the implementation of a prototype is introduced, at the end of the next chapter.

5 IMPLEMENTATION OF A PROTOTYPE

Just do it!

(Nike slogan)

A prototype of the ontology-based approach for supporting inspiration is developed. This prototype serves for evaluating the approach. In this chapter this implemented prototype will be introduced.

5.1 USED FRAMEWORK

The ontology is the main part of the proposed approach. This ontology needs to be sufficiently large. So, a representation of the ontology should be preferred that is appropriate to manage mounds of data and provide searching within the data efficiently. The conceptual model of the ontology is a graph. In general, there are many possibilities to represent a graph, for example adjacency lists[1], incidence lists[2], adjacency matrix[3]. Databases (DB)[4] can also be used to represent graphs. DBs provide efficient management and search in large collections of data. So, a DB seem to be an appropriate option to represent the ontology.

Using the prototype should be as easy as possible. A complicated interaction with the tool have to be avoided to not distract the user while generating ideas. Most DB systems do not provide a visualization of the data, and DB queries have to be made explicitly. Usually, some additional software tools need to be used for building a more comfortable user interface for accessing and visualizing data. MS ACCESS is a common DB that provides an intuitive visualization of the DB tables and allows interacting with the data easily. Furthermore, it contains tools for creating additional visual user interfaces and a programming environment, namely MS Visual Basic (MS VBA). So, MS ACCESS is an adequate DB to implement a prototype of the ontology-based approach.

5.2 REPRESENTATION OF THE ONTOLOGY

To represent the ontology in a DB, concepts, attributes, and values, and the relations between these elements have to be represented in tables.

Concepts, attributes and values are stored in separate tables. To provide storing knowledge from arbitrary domains, it should be possible

1 An adjacency list is the representation of all edges in a graph as a list [6]. For any vertex of the graph, there is a list containing all those vertices that are adjacent. Two vertices are adjacent, if they are linked by an edge.

2 An incidence list is a representation of a graph, that lists for any vertex of the graph all incident edges. An edge is incident to a vertex, if it connects the vertex to another vertex.

3 An adjacency matrix of a finite directed or undirected graph G on n vertices is the $n \times n$ matrix where the nondiagonal entry a_{ij} is the number of edges from vertex i to vertex j, and the diagonal entry a_{ii} is either twice the number of loops at vertex i or just the number of loops [7]

4 A database is a structured collection of records of data that is stored in a computer so that a program can consult it to answer queries. [13].

to have several concepts, attributes or values using the same name. Therefore, names do not have to be unique.

Also, relations in the ontology are stored in separate tables in the DB. To provide a generic structure of the ontology, and to allow an extension of possible relations in the ontology, the DB representation contains a table for any possible relation-signature, rather than a table for every distinct relation. A relation-signature tells which of the elementary types (concepts, attributes, and value) engage in a relation. For instance, the `fact` relation has the relation-signature 'CAV', that is: concept-attribute-value. As a consequence, relations such as `signature`, with relation-signature 'CA', and `domain`, with the same relation-signature, occupy the same table and create table records that are redundant.

Redundant table records have to be avoided in a DB implementation. For instance, a concept and an attribute that are related by a `signature` relation are also related by a `domain` relation. Therefore, it is sufficient to store only `signature` relations. The same holds for `specialization_of` and `abstraction_of` relations. Furthermore, the `akin_to` relation can be expressed by a concatenation of `specialization_of` relations. So, it is sufficient to store the `specialization_of` relations.

Storing concepts that are `similar_to` each other requires to calculate the HD (SHD and FHD) for any pair of concepts. The number of concepts to the power of two records would be created. But very likely only a small subset of those pairs of similar concepts might be used. Also, the calculation of the HD needs to be repeated after any change in the signature or facts of one concept. Therefore, it is more efficient to search for concepts that are `similar_to` to a specific concept only when required.

So, the DB contains tables of ontology-relations as follows:

- CA: contain `signature`
- AV: contain `range`
- VC: contain `value_is_concept`
- CC: contain `specialization_of`
- CAV: contain `facts`
- VVA: contain `opposite_of`

5.3 BUILD-UP OF THE ONTOLOGY

The ontology is build up in two steps. First, knowledge of the user is elicited; second, the ontology is extended my means of logical deductions.

The user has to express his knowledge in terms of concepts, attributes and values that are related. Using only the MS Access representation of the ontology, the user has to define each concept, attribute and value, before he is allowed to add the relation. For instance, adding a new `fact` requires, worst case, four times adding a record in a table. This disturbs the knowledge elicitation process. To provide typing in knowledge more comfortably, a form for data input was created (see figure 6). The form contains selection lists of all occurring concepts, attributes and values of the ontology, and allows to combine them. It is also possible to type in completely new elements. These elements will be added to the ontology and can be edited by the user later on, using editing forms, as shown in figure 7.

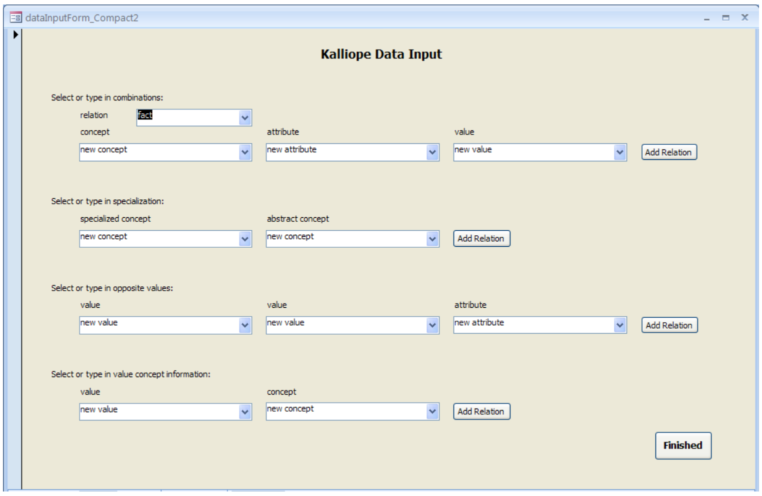

Figure 6. Input form for building up the ontology.

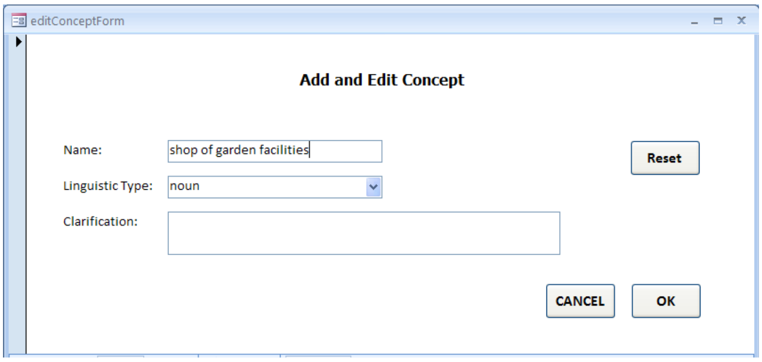

Figure 7. Form for adding and editing concepts.

After knowledge elicitation is finished, the ontology is complemented. If knowledge is added or removed from the ontology the deduced relations need to be updated. To keep the ontology consistent and correct, all deduced table records are removed. Then, the deduction rules that are described in section 4.2.2 are applied as long as new records are deduced. Applying the deduction rules terminates, because every relation tuple is allowed to occur only once. This algorithm is inefficient regarding the run time, but since complementing the ontology does not have to happen in real time, there is no urgent need for efficiency.

5.4 SYNTHESIZING INSPIRATIONAL SENTENCES

5.4.1 *Generation of Inspirational Combinations*

Inspirational sentences are generated using procedures that are programmed using MS VBA modules. Using MS ACCESS, any strategy can be expressed by means of SQL queries. An example of an implemented strategy is explained below.

The recombination strategy *substitute the value of a fact by a specialized value* is implemented as follows:

1. select an arbitrary fact relation (fact,c,a,v) of a current concept c
2. get the concept c_v that is assigned to value v:
   c_v = `SELECT concept FROM valueConcept`
   `WHERE relation = "valueIsConcept" AND value = v`
3. if such a concept c_v exists, select all specialized concepts of c_v and select a concept c_{spec} randomly
   `SELECT firstConcept FROM conceptConcept INTO tmpTable`
   `WHERE secondConcept =` c_v
4. find the according value v_{spec} to c_{spec}
   v_{spec} = `SELECT concept FROM valueConcept`
   `WHERE relation = "valueIsConcept" AND concept =` c_{spec}
5. if there is no value v_{spec} according to concept c_{spec}, create a new value, add this to the value-table, and add a `value_is_concept` relation)
   v_{spec} = `INSERT INTO ontologyValues ([name])`
   `VALUES (conceptName)`
   `INSERT INTO valueConcept ([value],[concept],[relation])`
   `VALUES (` v_{spec}, c_{spec}, `"valueIsConcept")`
6. post process element combination (c, a, v_{spec})

Any strategy also generates an explanation string. This explanation is intended to support an understanding of the assumptions and associations applied in the strategy. For the example above, this explanation is the following: *'V' is a value for attribute 'a' of concept 'c'. Value 'v' also occurs as a concept 'c_v'; 'c_v' has a specialization 'c_{spec}'. So, 'v_{spec}' is also a possible value for attribute 'a' of concept 'c'.*

Since not all strategies are equally useful and inspirational for every problem, the strategies are weighted. The prototype provides three kinds of weights: equal weight, a default weight, that can be set by the user, and a weight according to the rate of success, namely the ratio of useful suggestions to suggestions made using this strategy.

After an inspirational combinations is generated, it is put into an appropriate sentence pattern and presented to the user. The final sentences are presented in a form, shown in figure 8. The upper part of the form contains the inspirational sentence, an explanation of this sentence and some buttons for immediate evaluation of the suggestion. The lower part of the form is used for collecting ideas. All ideas and the according inspirational sentence are stored and can be exported as text files for external use.

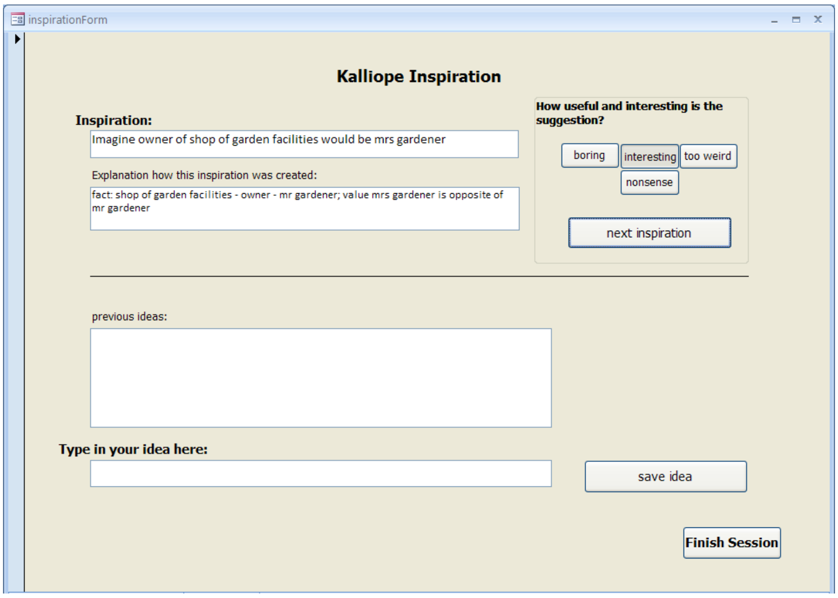

Figure 8. Form for presenting inspirational sentences. Under the inspirational sentence, also an explanation of this sentence is shown. Furthermore, the form contains a possibility for evaluating the inspirational sentence. The bottom part of the form contains an area to type in ideas.

5.4.2 *Dynamic Adaption of Parameters*

The prototype contains several parameters. Before inspirational sentences can be generated, the parameters HD, degree of kinship, problem distance, and the weight function for choosing the inspiration strategies have to be set up. Also, a set of control points have to be selected. The problem distance is applied to every initially selected control point, and extends the list of control points by all concepts that are within the problem distance. The final list contains all those concepts that are used for applying strategies.

The generated inspirational sentences can be evaluated immediately by the user, according to usefulness. A sentence can be asserted to be 'nonsense', or meaningful; a meaningful sentence can be either 'boring', or 'interesting', or 'too weird'. The user evaluation is fed back to the system, and parameters of the inspiration strategies are adapted. A boring suggestion increases the current intervals of HD and degree of kinship, whereas a sentence that is labeled 'too weired' decreases these parameters.

The number of ideas that are typed in by the user inspired by a sentence, is used to calculate the rate of success of the inspiration strategy that was used to generate this sentence.

Inspirational sentences are generated one after another in real time. After the user finished an inspiration session, the session parameters are reset.

EXAMPLES OF SYNTHESIZED SENTENCES Regarding the problem to *extend the service of a shop of garden facilities*, inspirational sentences are generated, Some sentences are listed below.

- Imagine employees would have special needs. (Explanation: associate attribute special needs that occurs with similar concept handicapped people with concept employees; strategy: suggest signature with similar attribute)
- Imagine employees would not be living being. (Explanation: scrutinize lattice: employees is an arbitrary specialization of living being; strategy: scrutinize lattice)
- Imagine retailer would be shop of garden facilities. (Explanation: associate concept retailer with arbitrary concept shop of garden facilities; strategy: associate arbitrary concept)
- Imagine customer would not have age. (Explanation: scrutinize signature: customer - age (age is not essential according customer being a living being); strategy: associate arbitrary concept)
- Imagine cleaning staff would not be employees. (Explanation: scrutinize lattice: cleaning staff is an arbitrary specialization of employees; strategy: scrutinize lattice)
- Imagine cleaning staff would be famous people. (Explanation: both are akin; strategy: associate akin concept)
- Imagine intention of shop of garden facilities would be teach. (Explanation: fact shop of garden facilities - intention - extend service; value extend service is concept; concept service has specialization teach; strategy: suggest fact with specialized value)
- Imagine shop assistants would have child. (Explanation: attribute child is not in the signature of shop assistants; strategy: suggest signature with arbitrary attribute)
- Imagine shop assistants would not have age. (Explanation: scrutinize essential signature: shop assistants - age (age is also an attribute of the abstract concept staff); strategy: scrutinize essential signature)
- Imagine retailer would be Michael Jackson. (Explanation: both are similar; strategy: associate similar concept)
- Imagine customer would have special needs. (Explanation: associate attribute special needs that occurs with akin concept elderly people with concept customer; strategy: suggest signature with akin attribute)
- Imagine purpose of shop of garden facilities would not be make money. (Explanation: scrutinize arbitrary fact: shop of garden facilities - purpose - make money; strategy: scrutinize arbitrary fact)

- Imagine customer would be landscape. (Explanation: associate concept customer with arbitrary concept landscape; strategy: associate arbitrary concept)
- Imagine customer would be Edward de Bono. (Explanation: both are akin; strategy: associate akin concept)

5.5 CHAPTER SUMMARY

A prototype of the ontology-based approach for supporting idea generation was implemented using a DB representation. The prototype synthesized inspirational sentences in real time. The inspiration strategies are implemented by means of SQL queries. The user can evaluate the generated inspirational sentences. This evaluation is fed back immediately to the system, and is used to adapt parameters of the inspiration strategies. The prototype will be used to evaluate the ontology-based approach.

6 EVALUATION OF KALLIOPE APPROACH

> Variety's the very spice of life, that gives it all its flavor.
>
> *(William Cowper)*

The Kalliope prototype was evaluated informally. The evaluation aimed at indicating whether guidance of a technique plays a role for the quality, quantity and variety of the generated ideas. The evaluation aimed at giving clues, whether the Kalliope approach in general is promising to support people with generating ideas, and whether the implemented inspiration strategies are feasible.

The main questions that should be answered by the evaluation are:

1. Is the Kalliope approach at least as useful as common techniques for supporting ideas generation?

2. Do people accept a computer program that synthesizes suggestions and do these generated sentences have an effect?

3. Is there a noticeable difference between the ideas generated in IGSs using different supporting techniques regarding quantity, quality and variety?

4. Does the Kalliope approach produce ideas of a higher variety?

5. Does the Kalliope approach produce more unusual and innovative ideas than common supporting techniques?

6.1 CRITERIA FOR EVALUATING THE IDEAS

It is very common to measure quantity and quality of ideas generated in IGSs. The quantity is a measure of the number of ideas created in an IGS. The quality describes appropriate, innovative and useful the ideas are to solve a certain problem. Some people, psychologists as well as inventors of creativity techniques, hold the opinion that a larger number of generated ideas always implies a larger portion of innovative ideas. A correlation between quantity and quality is presumed. Such correlation is difficult to verify, though. Indeed, the quality of ideas is usually assessed by asking the problem owner and other stakeholders, who have little material for comparison.

I propose to take also the `variety` of ideas into account in order to assess the performance of a creativity technique. A large number of ideas does not necessarily lead to more innovative ideas, if the ideas are very similar to each other. Perhaps the variety of produced ideas, when measured directly, is also a significant measure of success for a creativity technique.

6.1.1 *The Variety of Ideas*

The variety of ideas is a measure for the diversity of ideas. It describes how different the ideas are regarding attributes and assumed values of these attributes. The variety of ideas can be calculated using the Hamming distance (HD).

First, the ideas need to be classified. Using the approach of knowledge representation which is used in the Kalliope approach the characteristics of idea can be described. Similar to arbitrary concepts, ideas are described in terms of attributes and values. For every attribute the range has to be determined. In order to classify a set of ideas, the chosen attributes have to be operational (this means, the attributes have to be applicable to all ideas) and independent. These attributes are called 'classifiers'. All ideas have to classified regarding this classifiers, which means that every idea has to assume a value with respect to each classifier. This procedure is adapted from the Minerva-Centaur Design Approach (see 2.2.8).

After the ideas are classified the Hamming distance can be calculated. For every pair of ideas the Fact Hamming distance (FHD) and/or the Signature Hamming distance SHD is calculated. By means of the SHD the number of disjoint attributes are counted; by means of the FHD the number of disjoint values with respect to common attributes of both concepts is counted.

SHD and FHD of two ideas are calculated using the following formulas (both formulas were already mentioned in section 4.1.2).

$$SHD = \|(\phi(c_i) \cup \phi(c_j)) - (\phi(c_i) \cap \phi(c_j))\|$$

$$FHD = \|(\theta(c_i, a) \cup \theta(c_j, a)) - (\theta(c_i, a) \cap \theta(c_j, a))\|$$

$$a : a \in \phi(c_i) \wedge a \in \phi(c_j)$$

To make sure that all classifiers have equal influence on the FHD, these attributes have been assigned weights. The weight of a classifier depends on its number of values in the range: the larger the number of values, the larger the chance that two ideas are different with respect to the assumed value regarding this classifier, so the smaller its contribution to the Hamming distance.

The formula to calculate the weighted FHD of two ideas c_i, (c_j regarding all in common attributes is:

$$FHD = \sum_{k=1}^{n} w_k * \|(\theta(c_i, a_k) \cup \theta(c_j, a_k)) - (\theta(c_i, a_k) \cap \theta(c_j, a_k))\|$$

$$w_k = \frac{1}{\|\rho(a_k)\|}$$

$$a_k : a_k \in \phi(c_i) \wedge a_k \in \phi(c_j)$$

In this evaluation the variety of ideas was calculated using Assist. During this thesis some additional functions were added to Assist. For instance, some restructuring strategies were added to support idea generation, and also a module for calculating the FHD was implemented.

6.1.2 *Other Quality Criteria*

All generated ideas were evaluated according to subjective quality criteria. A group of assessors had to decide, whether the ideas are 'understandable', 'interesting', 'innovative', and 'appropriate to the task'. Also the assessors had to evaluate whether an idea are 'possible to implement'. A quality score is calculated: for every positive answer, a point is given; so any idea can get a maximum of five points.

6.2 evaluation setting and execution

The evaluation was executed at the Otto-von-Guericke Universitaet in Magdeburg. Participants of the IGSs were mostly Germans. To avoid difficulties because of translating the evaluation was realized in the German language. The participants could think and get ideas in their familiar mother tongue. To translate the ideas could have had a negative influence on the evaluation, because some participants might not be able to express all their thoughts in English language.

Four different techniques for supporting idea generation in staged IGSs were performed. The techniques were chosen with respect to their guidance of participants.

spontaneous non-guided brainstorming : The participants got the task and had to generate ideas immediately and without any advice. A moderator was present, but intervened only when the participants started to evaluate ideas or used inhibitory phrases, for example, 'this does not work' or 'this already exists'.

guided brainstorming with preparation : The participants got the task the day before the IGSs and were asked to write down everything they know about the domain. During the IGSs the moderator red out some elements from the elicited knowledge and gave hints to transfer things, for example 'bring things from indoor to outdoor use', 'think of specific difficulties'.

guided association technique with preparation : The participants got the task the day before the IGSs and were asked to write down everything they know about the domain. During the IGSs the moderator gave advice and tried to guide the participants to some detours via associations, for example 'Toys are usually used with the hands. Who else is doing a lot with his hands?'. Any inspirations given in the IGSs based on creative thoughts of the participants and mainly of the moderator.

kalliope support with preparation : The participants got the task the day before the IGSs and were asked to write down everything they know about the domain. The elicited knowledge was fed into the database of Kalliope prototype. During the IGSs the moderator red out the synthesized sentences proposed by the Kalliope prototype. Sometimes the moderator had to 'translate' sentences that were difficult to understand, because of grammatical incorrectness. Furthermore, the moderator asked the participants to evaluate the suggestions.

The chosen techniques are very generic. Rather than attempting to find differences between various creativity techniques, it was intended to see if there is a difference between techniques that do not rely on making thoughts explicit, and those (like Kalliope) that do. The evaluation aimed at giving clues whether the guidance and the preparation are meaningful for idea generation and whether there is a significant difference in variety.

Each technique was tested in two trials, with three to five participants and a duration of half an hour each. The participants were mainly students and young employees, between 20 and 35 years old, with a background in computer science, industrial design, or social science. The same task was executed in all IGSs.

TASK *Generate ideas for a new toy for children at elementary school level.* The task was restricted by the following constraints:

- target age: 6-10 years
- both for boys and girls
- contains sustainable materials
- possible to produce in Europe
- production costs at most 10 Euro
- price to sell at most 30 Euro
- follow-up costs are welcome (add-ons, spare parts, or commodities)
- for sale in summer

The participants of three techniques, guided brainstorming, association method and Kalliope support, had a preparation. All participants got the task one day before. The moderator asked the participants to write down everything they know about the problem domain. The moderator gave some parameters and questions for consideration:

- Who plays with toys?
- When do people play with toys?
- Where do people play with toys?
- What are difficulties with playing with toys?
- What kinds of toys to exist?
- What materials are toys made of?
- How are toys used?
- What are processes of related with toys?
- What are parts and elements of toys?
- What are general properties of toys?
- Why do people play with toys?
- What are terms of toys/ playing with toys?

6.2.1 *Execution of the IGSs*

Every evaluation session had a duration of half an hour. It was not always possible to assure five participants in every IGS, because some participants canceled at the last moment or did not appear. Last-minute replacement of participants was not possible, because in most IGSs participants had to have a preparation.

unprepared non-guided brainstorming One session with four people (one did not appear) and a session with five participants was executed. The participants of the IGSs got the task and had to generate ideas immediately afterward. The moderator had to motivate the participants to write down all ideas, even if things already exist or ideas are only fragments.

guided brainstorming Two IGSs with five participants each were executed. In the beginning the moderator red out the task and some materials, purposes and locations of toys that occurred in the earlier knowledge elicitation session. During the IGSs the moderator seized some remarks and ideas as hints to guide the idea generation process and animate participants to think ideas further.

guided associating One IGS with four (one canceled) and one IGS with three participants (one canceled, one did not appear) were executed. In the beginning the task was red out. Furthermore, some properties from the knowledge elicitation process were taken (for instance, 'material', 'activities') and red out to the participants. The moderator tried to create artificial associations to other domains, for instance, by means of questions: What other things have wheels? Who else is doing something/working with the hands?

kalliope prototype Two IGSs with five participants each were executed. The knowledge from previous preparation sessions of all participants was used to fill the ontology of the prototype. In the beginning of the session the moderator red out the task. During the IGSs the moderator used only the prototype. No additional questions and suggestions were created to avoid interfering the effect of the Kalliope prototype. The moderator red out the synthesized inspirations and if necessary, put them into a proper sentence structure or explained how to use the suggested sentences.

6.3 hypothesis and expectations of the evaluation

According to the hypothesis of this thesis, guidance is the key to support innovative idea generation in people. I believe this to be true in particular for guidance on the basis of problem domain-related knowledge and even knowledge from other domains. I assume that the amount and variety of the produced ideas increase with the amount of guidance.

I expect less guided techniques, for instance brainstorming, to produce a lot of ideas, but also a lot of common and not surprising ideas.

I am the most pessimistic about unprepared and unguided brainstorming, because people are confronted with a problem and have to generate ideas to solve this problem immediately. They have no time to think about the problem and they are on their own while they have to generate ideas. I expect the association technique to work better than brainstorming, because it guides idea generation via chains of connected association. To find such detours challenges the abilities of the moderator. The Kalliope prototype I expect to be at least as good as common techniques.

6.4 EVALUATION RESULTS AND INTERPRETATION

Before the results of the evaluation are presented, first some general impressions are given.

6.4.1 *Observations during the IGSs*

The first significant observation was, that in little prepared and little guided IGSs, people tend to think in a rather constrained manner. They only produce small variations to things they are familiar with, such as toys they used in childhood. So, preparation and guidance seem to help people to loosen up their self-inflicted constraints.

IGSs using unprepared non guided brainstorming proceeded tenaciously. Participants had obviously difficulties to generate ideas and constrained themselves. Guided brainstorming created a lot of ideas fluidly.

Performing the association technique was difficult, because the participants had problems to follow the association advices of the moderator. They did not see the reason to do this and returned to the original task soon.

During the session using the Kalliope support, some technical difficulties occurred. The prototype took a long time for calculating the inspirational sentences. Also the system crashed in between. So, some longer delays occurred between the presented inspirational sentences. The participants mostly had no difficulties to use the suggestions and to create ideas. The generated ideas were based on the inspirational sentences with respect to the given task. Only some difficulties occurred with synthesized associations (that are sentences like: 'Imagine concept <x> is a <z>'). Participants were irritated by the 'is a' phrase in the sentence. In general, participants seem to be less constrained in their thinking, they allow being inspired and guided by the synthesized sentences. Also, the participants were amused and intrigued, rather than distracted, by Kalliope's strange and unorthodox suggestions.

6.4.2 *Ideas Generated During the IGSs*

The complete lists of ideas generated during the IGSs is shown in appendix D.1. Various ideas according to marbles occur, also typical games like 'Mensch aergere dich nicht', 'verstecken' and 'Schnitzeljagt' have been varied. Exceptional ideas like 'Huepfschaufeln' (shovels that can be used for jumping) or 'Schaufelhandschuhe' (shovel-gloves) as a result of the suggestion 'Imagine shovel would be rubber' occurred during the IGS using Kalliope prototype.

A total of 190 ideas have been generated during eight IGSs. Some ideas occur several times or as variation in several sessions, for example various ideas according to marbles and marble attachments. During the analysis, some ideas have been deleted, because these ideas describe classifying attributes, for instance, 'indestructible toys' or 'toys for learning'. These ideas have become classifiers in the analysis of the ideas.

6.4.3 *Analysis of Ideas*

The number of generated ideas per session was counted.

All generated ideas have been evaluated according to their quality. Five people gave independent assessment of the quality of the ideas regarding the defined criteria by means of a questionnaire. The tables containing the results of quality assessment are listed in appendix D.2.

The variety of ideas generated have been calculated using Assist. For calculating the variety of the ideas, meaningful classifiers had to be chosen. This has turned out to be not trivial, because finding operational classifiers is quite difficult, for example, to distinguish 'marbles' from a 'bakery mix game' and also from a 'kite construction kit'. Also, some ideas were only fragments or very vague, so it was difficult to classify them. Furthermore, some ideas were characteristics of toys rather than specific toys. These ideas were interpreted as classifiers. For example, the idea 'toys for grandparents' became a classifier 'target user' with values 'elderly people', 'children', or 'toys for learning' became a classifier 'purpose' with values 'learning', 'entertainment' and so on.

With respect to all evaluation criteria the average value and standard deviation for every supporting technique were calculated. In the context of the evaluation, the symbol σ is used for standard deviation and the symbol μ for average value. Average value and standard deviation are calculated using MS Excel functions:

$$\mu = \frac{\sum_{i=1}^{n} X_i}{n}$$

$$\sigma = \sqrt{\frac{\sum_{i=1}^{n} (X_i - \bar{X})^2}{(n-1)}}$$

6.4.4 *Quantity of Ideas*

IGSs using unprepared and unguided brainstorming the fewest ideas were generated (21 + 8 ideas). IGSs using prepared and guided brainstorming have produced a lot of ideas (37 + 18 ideas). IGSs using prepared and guided association technique generated less ideas than guided brainstorming (13 + 20 ideas). IGSs using prepared Kalliope support generated in total the most ideas (28 + 37 ideas).

The comparison of the average number of generated ideas in the different supporting techniques is shown in figure 9. The average number of ideas is based on the absolute number of ideas produced in each session, not relative to the number of participants. The idea output of the group is considered as a whole, in particular, the number of ideas is not proportional to the group size.

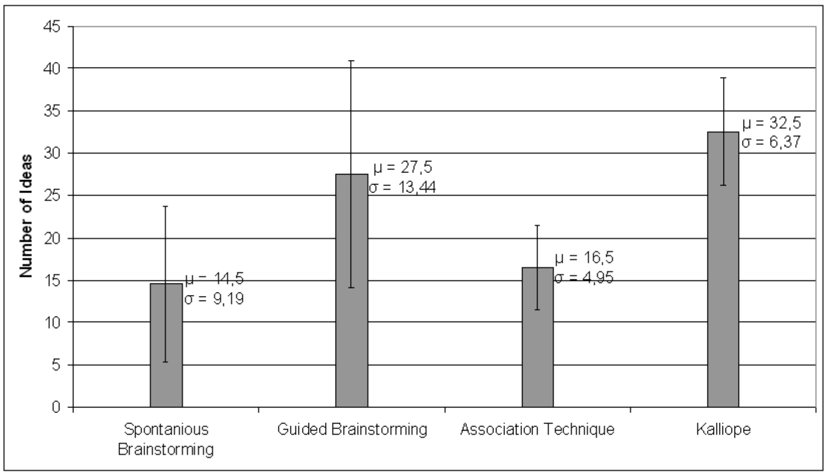

Figure 9. Average value and standard deviation of the number of ideas produced in all idea generation supporting techniques.

Figure 9 shows a smaller standard deviation of the amount of ideas in more guided techniques. Although, of course, the group sizes are too small to allow firm conclusions, I tend to recognize my assumption about the relations between guidance and amount of ideas: unguided brainstorming produces less ideas than more guided techniques, especially compared to Kalliope.

Also from figure 9, it seems that association techniques have a somewhat inferior performance than both guided techniques - in particular Kalliope. This result can be explained with difficulties in applying this technique. The participants had difficulties to follow the moderation advice and the moderator was not experienced and ably to guide on association detours. Therefore a lot of delays and confusions occurred that disturbed the idea generation process.

From figure 9, it appears that Kalliope performs quite good with respect to the number of ideas. The sequence of very different and also unusual inspirations generated by the Kalliope prototype might be a reason for the large number of generated ideas. Once a participant gets used to working with Kalliope, she/he seems to be able to relax her/his self constraints and allowmore unorthodox ideas to enter the discourse.

6.4.5 *Variety of Ideas*

With respect to the variety of ideas, a significant difference between all prepared and guided supporting techniques was not discovered. Average and maximum HD are shown in figures 10 and 11.

Average HD is comparable with values between 5,3 and 5,7 in all

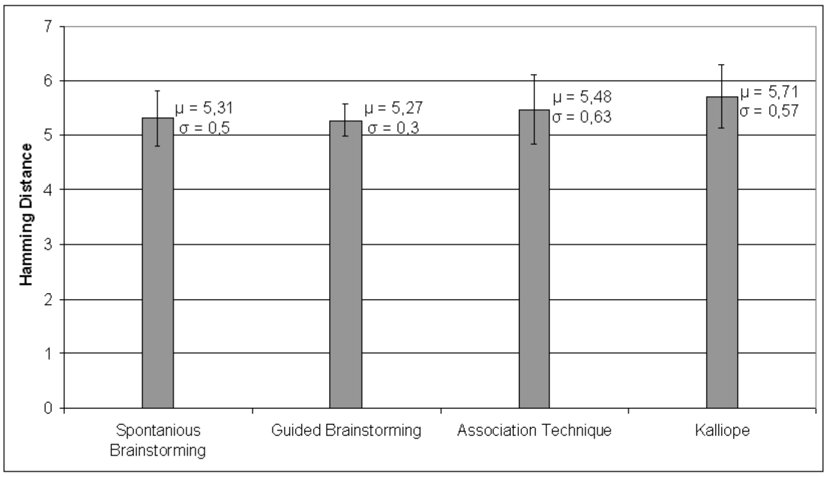

Figure 10. Average value and standard deviation of average HD of ideas produced in the idea generation supporting techniques.

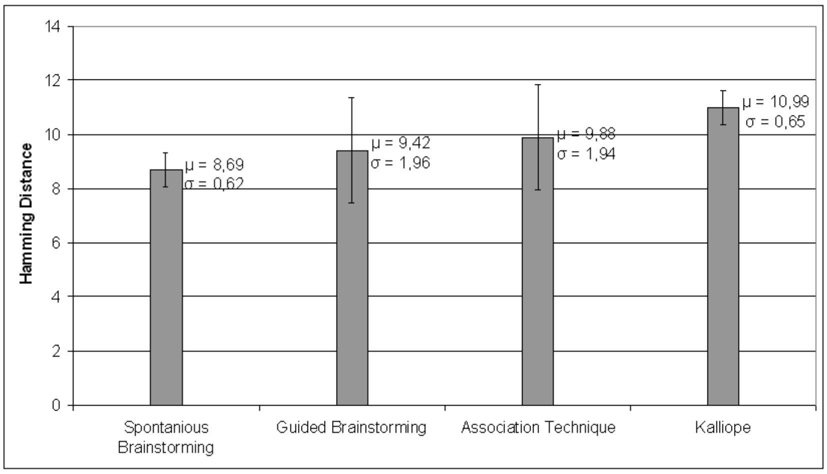

Figure 11. Average value and standard deviation of maximum HD of ideas produced in idea generation supporting techniques.

techniques. Also the standard deviations of average HD are comparable and overlapping between the techniques. The maximum HD has a slight tendency to increase slowly with the guidance of the technique.

These techniques seem to be very sensitive to the guidance and abilities of the moderator. From figures 10 and 11 I tentatively conclude that Kalliope is at least not worse than other techniques with respect to the variation in the produced ideas.

Comparing guided and non guided supporting techniques (see figures 12 and 13), I tend to conclude that guided techniques in general are certainly not worse for the variety of ideas produced in an IGS.

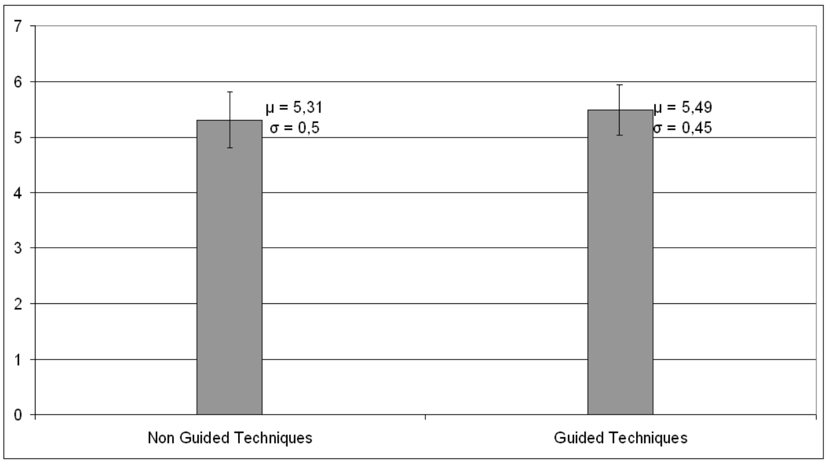

Figure 12. Average value and standard deviation of average HD of ideas produced in idea generation supporting techniques.

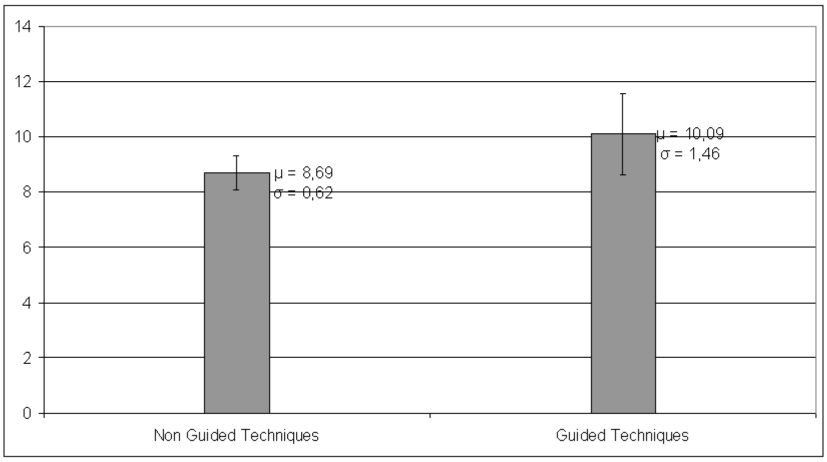

Figure 13. Average value and standard deviation of maximum HD of ideas produced in idea generation supporting techniques.

6.4.6 *Quality of Ideas*

In general both guided and non guided techniques produce equally good ideas. Only guided brainstorming produces significant better results than the other techniques. According to the quality of ideas, guided brainstorming was most successful (see figure 14). The total quality score, as it combines various criteria, is difficult to interpret. Therefore, the techniques were evaluated with respect to each of the quality criteria. According to the criteria 'interesting' (see figure 15), 'appropriate to the task' (see figure 16) and 'possible to implement' (see figure 17) common techniques, especially guided brainstorming, produce better results than Kalliope.

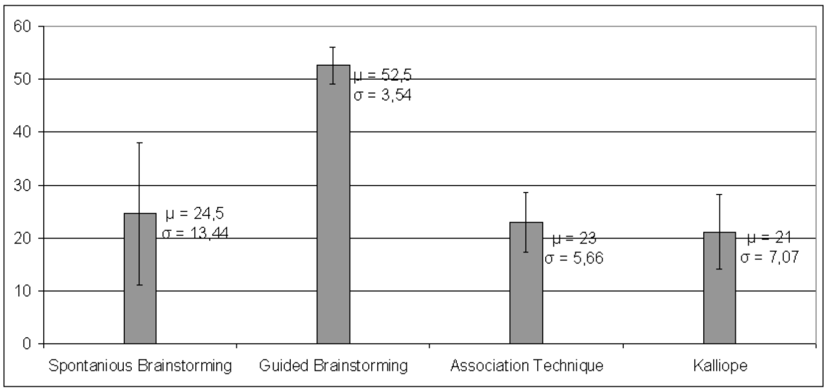

Figure 14. Average value and standard deviation of quality score of all idea generation supporting techniques.

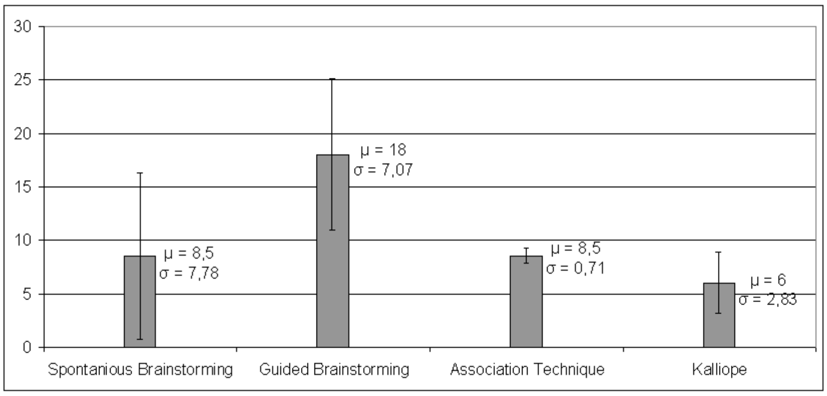

Figure 15. Average value and standard deviation of the number of interesting ideas generated in the idea generation supporting techniques.

According to the assessment of the evaluators, Kalliope can certainly not come in the place of the standard techniques. There is one aspect, however, where Kalliope gives a solid improvement over spontaneous

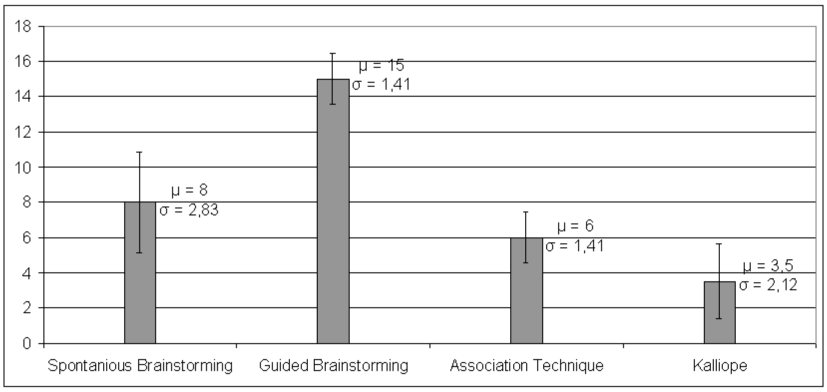

Figure 16. Average value and standard deviation of the number of appropriate ideas generated in the idea generation supporting techniques.

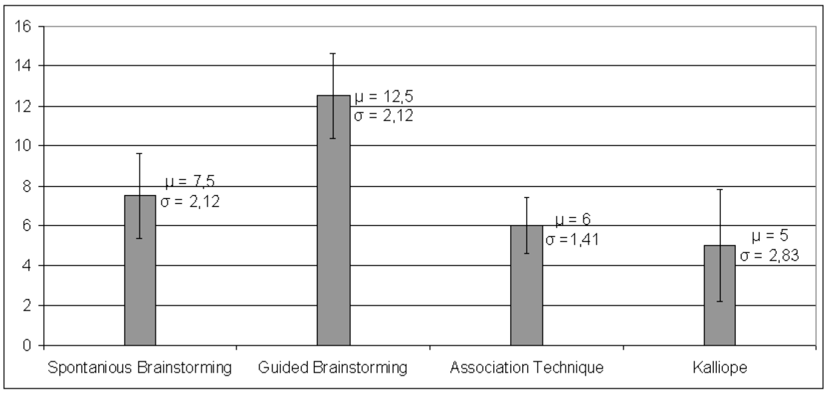

Figure 17. Average value and standard deviation of the number of ideas assessed as 'possible to implement' generated in the idea generation supporting techniques.

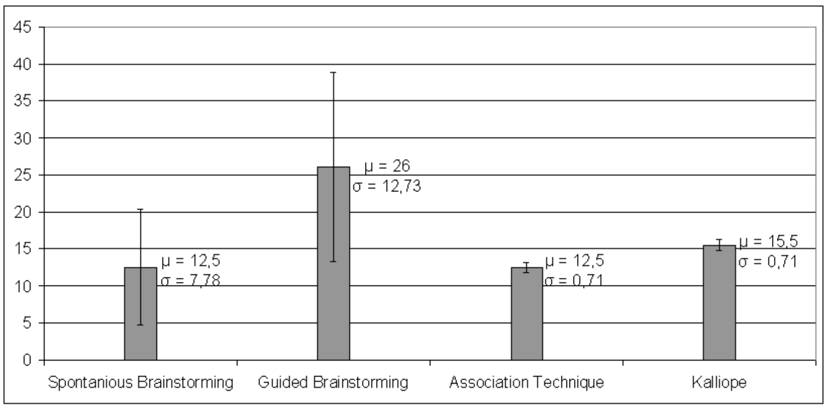

Figure 18. Average value and standard deviation of the number of understandable ideas generated in the idea generation supporting techniques.

brainstorming and the association technique: when it comes to innovative ideas (see figure 19), Kalliope is a very interesting alternative. It performs almost as good as guided brainstorming, despite that it does not require a moderator to inspire their innovative ideas. So from the criterion of 'quality of resulting ideas', I conclude that the best approach consists of a combination of techniques, where either guided brainstorming or Kalliope should be a part of this mix to ensure the innovative contents.

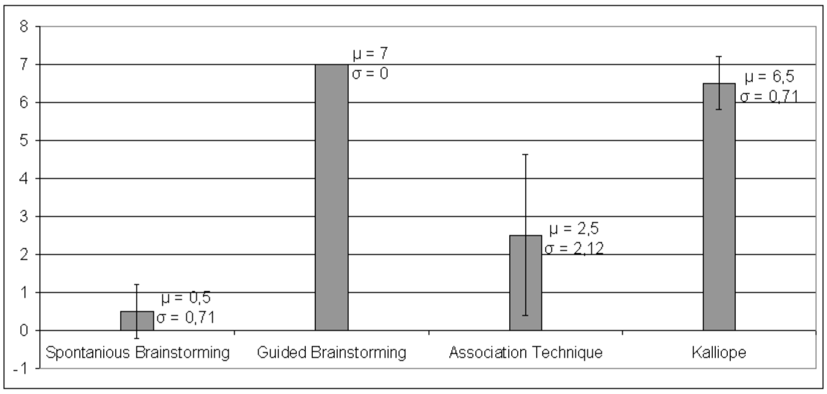

Figure 19. Average value and standard deviation of the number of innovative ideas generated in the idea generation supporting techniques.

6.5 conclusions of the evaluation

The target questions of the beginning of this evaluation can be answered as follows.

1. The developed knowledge based approach is not less useful than common techniques for supporting idea generation.
2. People are willing to to work with computerized synthesis of inspirational suggestions.
3. IGSs using guided techniques seem to perform better with respect to quantity, quality and variety of generated ideas.
4. For the Kalliope approach to compete with other guided techniques in terms of variety, it is at least necessary that the knowledge base is significantly extended, preferably with facts from other domains. Once Kalliope will be used in IGSs, this will happen automatically.
5. Kalliope's ability to stimulate innovative ideas is at least as good as unsupervised techniques, and unlike guided brainstorming, it does not need a skilled and creative moderator to do so.

The ontology that is used in the Kalliope approach is meant to be re-used. The performed evaluation used a newly build up ontology that contained only information from the former knowledge elicitation. So the generated suggestions base on a limited ontology only and were not that surprising as they were expected. I assume, the more Kalliope will be used and the more knowledge from several domains it will contain, the better and the more surprising ideas will be generated.

IGSs with a human moderator depend critically on the quality of the moderator. With Kalliope, this problem is reduced. One still needs a capable moderator to cast the elicited knowledge in the form of concepts, attributes, values and relations, but this is an analytic task much more than a creative, synthetic task - and it does not rely on the moderators imagination skills.

6.6 CHAPTER SUMMARY

A brief evaluation was performed that aimed at indicating whether the guidance plays a role for supporting idea generation in professional, moderated IGSs. Four different supporting techniques of a different grade of guidance were assessed with respect to quality, quantity and variety of ideas generated. One of the techniques used the Kalliope prototype. The Kalliope prototype was evaluated for being accepted by participants of IGSs, and for working successful with inspiring people to generate a lot of unusual and innovative ideas.

7 CONCLUSION AND FUTURE WORK

> Around here, however, we don't look backwards for very long. We keep moving forward, opening up new doors and doing new things... and curiosity keeps leading us down new paths.
>
> *(Walt Disney)*

7.1 SUMMARY

The goal of this thesis was to develop an approach to support people to generate more innovative ideas.This thesis was motivated by a growing need for professional and reliable techniques for idea generation in order to - for example - design new products and services. I have developed a systematic approach to support idea generation by means of synthesizing inspirational questions and suggestions that are related to a problem. The leading idea of this approach was inspired by the observation that people solve problems by rethinking, scrutinizing and restructuring them. After the Greek muse of science and epic poetry, I have named this approach `Kalliope`.

First, an approach based on grammars only was developed. This has turned out to be not sufficient, because it lacks domain specific knowledge and generated too many meaningless sentences. It was not possible to develop a grammar that is both generic and domain specific enough to generate inspirational sentences that to scrutinize domain specific knowledge. Therefore an ontology was created that contains knowledge of several domains. Knowledge from arbitrary domains is expressed in terms of concepts, attributes, and values and is structured in the ontology. In order to synthesize inspirational questions and suggestions, this knowledge is restructured. A set of heuristic strategies was developed to generate meaningful combinations of knowledge elements stored in the ontology. These strategies are inspired by thinking strategies that were observed by introspection and in creativity techniques. The recombined knowledge is processed to comprehensible sentences. Also for every inspirational sentence an explanation of the applied thinking strategies is generated. The synthesized sentences are presented to the user, evaluated according to meaningfulness and weirdness. The feedback of the user is immediately fed back to the system to adapt parameters of the strategies. The inspirational sentence and all ideas that were generated inspired by this sentence are collected. A prototype of the Kalliope approach was developed and tested in an informal and brief evaluation.

Furthermore, a new evaluation method was developed. Beside quantity and subjective quality criteria, I have introduced variety as a new quality criterion for evaluating ideas. The variety is a measure for the diversity of ideas. Ideas are classified and compared to each other. The variety is calculated using the Hamming distance regarding classifying attributes of these ideas. By means of the variety an objective criterion for evaluating ideas is available.

7.2 CONCLUSIONS

Synthesizing meaningful and domain related sentences in order to inspire people is elaborate. It requires a lot of knowledge of several domains. I propose to use a structured, knowledge based approach to support people to get innovative ideas. The Kalliope approach realizes this to a certain extent. I can assert the Kalliope approach to be at least as good as common techniques for supporting idea generation. Participants of IGSs using the Kalliope prototype have assessed the supporting approach as being helpful and interesting. Using the Kalliope prototype a lot of unusual ideas were generated compared to ideas generated using common supporting techniques. The variety seems to be a meaningful criterion for evaluating ideas. Therefore, I firmly believe the Kalliope approach is promising to be developed and investigated further.

7.3 FUTURE WORK

This thesis can be only the basis for a professional knowledge based approach to support idea generation. A lot of improvements have to be done until the theoretical approach and prototypical implementation can become a professional and reliably working framework.

The ontology could make use of external knowledge bases to be completed and enriched. I believe the richer the ontology, the better the inspirational sentences. To be able to manage such a complex ontology, another database system should be used, that is able to manage large mounds of data. I expect MS Access to be limited soon.

Furthermore, the Kalliope supporting system could be implemented as a web-based distributed multi-user application. The system could be used by a group of people in parallel. So IGSs can be performed with people that are locally distributed. Furthermore it should be possible to have IGSs without a specified time frame. A distributed web-based system allows non-synchronous operation (for example, participants can work on their own convenience). A skilled and creative moderator is no longer necessary.

Also, an automated interviewing system could be developed for supporting an intuitive knowledge elicitation.

The current prototype could be optimized. The search algorithm for finding recombinations and new associations of knowledge elements is only a naive implementation; it is too slow for a real time application. The speed of the calculation has turned out to be relevant, because longer delays disturb the flow of generating ideas in an IGS.

Some visualization could be implemented. Currently the user can find out contained elements and relations in the ontology only by observing the data base tables. Perhaps it would be useful to provide some visualizations of the ontology to provide a more comfortable use and a better understanding of the system.

A more elaborate postprocessing machinery could be developed to build inspirational sentences that are grammatically correct.

I have not put effort in a well-defined and evaluated user interaction system. For professional use of any technical system the user interface and the interaction model play a significant role. To provide successful usage and avoid mistakes in using the system, the interaction should be designed diligently.

The improved Kalliope prototype should be evaluated in a more sophisticated and statistically relevant evaluation to assess the usefulness of the Kalliope approach and to test the usability of the system.

Also, the benefit of the new evaluation criterion `variety` should be investigated further.

The Kalliope approach is related to the Minerva-Centaur Design Approach. The Kalliope approach replaces the missing functionality to generate the first initial ideas, that can be analyzed using the Assist system. Both approaches can be coupled and combined to provide an optimized work flow. Ideas could be fed into the ontology and made subject to restructuring and recombination strategies. Clustering of ideas can be applied to restructure knowledge and to develop ideas.

7.4 Personal remarks

This thesis contains much of my own creativity and skills. I am glad that I got the chance to work with a great thinker and skilled person Kees van Overveld and to do a little bit of scientific research. This is the first time that I have the feeling to have done something that is valuable to be written about. I am still curious to develop the approach further.

I aim at understanding creativity by demystifying and analyzing it. I am convinced that an attitude of scrutiny can overcome the natural tendency to take things for granted. In my opinion, the synthesis of creativity and mathematics is amazing. But the idea to use mathematical methods to improve creativity seems to put off most people. A lot of people scare away from mathematics and take it as a strange mystery, they do not understand. But mathematics is a language, ideally suited to be precise and rigorous. As with everything else, mathematics should be used with a clear intention in mind: then it becomes a means and a methodology to achieve a goal.

This thesis is based on my creativity and a lot of hard work. I had to overcome a lot of difficulties; there is a lot that I can learn and improve.

Now as this thesis is written down, I can enjoy it again.

A

APPENDIX: EXAMPLE PROBLEMS AND ACCORDING INSPIRATIONAL QUESTIONS

A.1 EXAMPLE PROBLEM 1

Problem 1: A shop selling garden facilities wants to extend its service.

1. How could you take advantage of of the spare capacity in the winter?
2. Why don't you take a green hat view to look at the contracts with the lawn-mower retailer?
3. What would the pope buy in your shop?
4. Imagine you can see through walls, would lawn-mowers look different?
5. Imagine the landscape would turn to into desert, what would you do?
6. Someone's children want to work in the garden, what kind of tools would you give to them?
7. Do you have an idea how people in stone ages took care of their gardens, with what kind of tools?
8. What could you do to make your business smaller?
9. How could you sabotage the shop of a business rival?
10. What else are people doing during lawn-mowing?
11. How do handicapped people (blind, missing an arm, wheel-chair users, mentally handicapped) take care about their gardens, what difficulties do they have?
12. Think about a garden on the roof of a high building, how to work there?
13. Think about cemeteries or balconies, what are the differences to work there compared to ordinary gardens? (different areas: extremely wide or narrow, mono cultures, extreme climates, on mountains: terraces)
14. What difficulties does your grandmother have with working in the garden?
15. Imagine one machine that could do everything in the garden. How could this machine look like? What would be the main tasks of this machine?
16. What are the most important/ most difficult kinds of work in the garden?

17. Assume it is very hot, how could lawn-mowing be refreshing?
18. How does your wife clean the kitchen?
19. What kind of smell do you like most in your house/ in your garden?
20. Do you like garden very clearly structured or a little bit wild looking? How does your office look like?
21. What kind of things do you find lying on the ground in the garden (nuts, wood, olives, birds)?
22. What do sheep/ pig/ chicken like to eat?
23. What parts of the body are hurting after a few hours of lawn-mowing/ different kinds of working in the garden?
24. What would people do instead of working in the garden?
25. Take the blue hat and think about working in the garden, what could be optimized?
26. Take the blue hat and think about your shop, what could be optimized?
27. Take the red hat, what do you like most in your shop?
28. Take the red hat. What is the nicest aspect of working in your shop?
29. What do a shop of garden facilities and a hospital have in common?
30. Imagine tomorrow you would own a shop of dentist-tools. What would be different?
31. Take the black hat looking at the contracts with your customers?
32. Remember when you were a young child, what did you like most about being outside?
33. Did you ever had any rendezvous somewhere outside? When and where? Why there?
34. What product was your last flop/ disappointment?
35. Imagine you are a dog, what kind of things would you find interesting in your shop?
36. What would an Eskimo buy in your shop?
37. What do your customers often forget to buy in your shop for which they have to come back?
38. What is destroyed during a wind storm in a garden, what would be helpful to clean up afterwards.
39. Imagine there is no electricity/ water available in a garden, what kind of tools would not work any more?

40. What could a champion farmer buy in your shop?
41. With what kind of tools do most of your customers have difficulties?
42. What kind of tools are the most dangerous ones and cause a lot of accidents? Why?
43. What sorts of regular customers do you have?
44. Imagine there would be no gravity. What difference would this make for working in the garden/ working in the shop?
45. Imagine money would be abandoned and you would not sell things any more. What else could you do with your tools? What things need to be changed in your shop? How could your shop deal with customers then?
46. What is the difference between your shop and any other shop of garden facilities?
47. Imagine there would be a Tsunami, and a lot of gardens would be damaged. How could your shop help afterwards?
48. Do you know the movie 'The Birds' by Alfred Hitchcock. How could you serve the birds to stay somewhere. How could you help the people?
49. Imagine your shop would be on the moon, what would be different?
50. What are the advantages of extending the service? What are the disadvantages?

A.2 EXAMPLE PROBLEM 2

Both problems are similar, the service operation shall be improved with keeping the current capacities of facilities, employees and stakeholders in general.

Problem 2a: How can the waiting times/ serving times at a hospital be shortened.

1. Why is waiting so boring/ annoying/ dangerous?
2. What are people doing while waiting?
3. What kind of music do you play? What effect does this music have on the patients?
4. What kind of patients do you serve mostly?
5. Where do these patients look at while waiting?
6. Is it allowed to eat/ drink/ smoke in the waiting area?
7. Imagine you are waiting for the bus, what are you doing there, what is different to waiting in the hospital?

8. Imagine you are a public service center, what are the differences in waiting there?
9. Where do people have to wait? Imagine people could wait somewhere outside...
10. What do you think about when you are waiting for the doctor?
11. Have you ever been frustrated of waiting because you could have used the waiting time to do something different, for example go shopping, read email, make calls?
12. Imagine people would like to come to the hospital for social events, what events could that be?
13. What kind of people do sit together/ next to each other (women, elderly people, youngsters)?
14. Remember when you where were a child going to the doctor. What were you afraid of mostly? What were you pleased and happy with?
15. As a child, what did you like most at the doctor/ hospital?
16. How did hospitals look like in ancient ages?
17. Which smell do you like/ dislike most at the doctor? Which smell do you remember?
18. What is the difference between a hospital for human beings and for animals?
19. Imagine there would be a hospital for plants, how could this look like?
20. Do people have to come to a certain point more than once?
21. Who are the people mostly speaking to?
22. What is the main task of the people called at most often (service, staff, nurses etc.)
23. How could you scare people best in the hospital?
24. Where do people laugh mostly? How to make a funny scenario?
25. What is the difference between a circus and a hospital?
26. What is the most expensive thing in a hospital?
27. What kind of food do you serve your patients or guests in the hospital?
28. When is the food available?
29. How is the price of the food in your hospital?
30. Who is responsible for the cafeterias?

31. How long do patients have to wait for a appointment with a specialist? What do they do until the appointment?
32. What is the difference between your hospital and a monastery?
33. What do you do, if somebody dies in your hospital?
34. What do you do, if a child is born in your hospital?
35. When is your hospital very busy, which season, with respect to holidays etc.?
36. When do most of your staff goes on holiday?
37. How could you/ What could disturb the system of your hospital completely?
38. How could you enlarge the queues in your hospital?
39. How could you frustrate your patients/ customers/ staff?
40. How many patients/ customers/ staff do you expect to loose by frustrating them?
41. Imagine you would have unlimited resources of space, staff, money, what would you do?
42. Imagine you would nearly have no resources, what would you change in your hospital?
43. Imagine you would start a hospital in a very poor area somewhere in the world, what would you do first?
44. What kind of injuries/ diseases is a doctor able to medicate using his medicine bag only?
45. What is the difference between a house doctor and a doctor working in a hospital?
46. Which color dominates in your hospital? Imagine it would be the complementary color, how does this feel?
47. Imagine you would have to color the different service areas in your hospital, which areas would you define and which color would you assign to them?
48. Is there a very noisy area in your hospital? Why is that area that noisy?
49. Imagine this area would be completely silent, what would this situation change?
50. What could a narrator do in your hospital, or a clown, an artist or a sport professional?
51. Imagine there would be a music school next to your hospital, and you could hear all the music exercises and some concerts too during the day. What would this mean to your hospital, to people waiting in queues?

52. How do blind people find the way in your hospital?
53. What would Mother Theresa do in your hospital?

Problem 2b: How could we optimize the facilities of our university? Serve the students, guests, deal with exceptions faster and more successful?

1. Who is the first person you speak to, if you arrive at the university?
2. What kind of people come to the university?
3. What is the reason for people to come to the university? What is their intention/ purpose?
4. How long do people stay at the university?
5. Who is responsible for exceptions?
6. Imagine you want to make the people angry and frustrated. How would you do that?
7. What do people remember when they come to the university?
8. How much languages are spoken at the university? Among the students, among the staff?
9. Where do people go to very often? Where do people meet each other usually?
10. When do people meat each other very often? Why?
11. What are the main common places of the university where people meet each other?

B

APPENDIX: EXAMPLE GRAMMAR

For to the task of *extending the service of a shop of garden facilities*, some grammar examples have been developed. Some of these grammars involve questions taken from creativity techniques, some questions build upon questioning strategies from the natural example questions A. The grammar producing the most useful sentences is described below.

The start variable is always <inspiration>. Terminals and nonterminals are not listed, because listing the production rules is sufficient to understand the grammar content.

This example grammar related to the task to extend the service of a shop of garden facilities.

<inspiration> ::= <focus> | <imagine> | <whatWould> | <whatIf> | <thinkAbout> |<6hats> | <invert> | <simpleSolution>
<focus> ::= <whatProblems>
<imagine> ::= Imagine <people> <do> <something> <somewhere>. | Imagine your are <livingBeing> <preposition> <domainRelated-Places>.
<whatWould> ::= What would <livingBeing> <do> <somewhere>?
<whatIf> ::= What if <things> would <be> <somewhere>?
<thinkAbout> ::= Think about <object>.
<6hats> ::= Why don't you take a <hatColor> looking at <domainRelatedObject>?
<invert> ::= <invertIntention> | <invertDis-Advantages>
<simpleSolution> ::= How could you <goals>? | How could <domainRelatedPeople> <domainRelatedActivities> <somewhere>?
<whatProblems> ::= What problems have <people> with <do>ing <something>? | What problems have <people> at <domainRelated-Places>?
<people> ::= <famousPeople> | <domainRelatedPeople> | you | someones children | somebody | your grandmother | a secretary
<do>
<something> ::= <domainRelatedActivity> | <somewhere>
<somewhere> ::= <preposition> <place>
<livingBeing> ::= <people> | <animal>
<preposition> ::= in | at | on | under | next to
<domainRelatedPlaces> ::= your shop | a garden | a park
<things> ::= a desk | a cashpoint | a teaspoon
<be> ::= be | lie | stay | sit
...

This grammar produced inspirational sentences as follows:

1. Imagine someone's children do <something> <somewhere>.
2. Why don't you take a black hat looking at <domainRelatedObject>?

3. What problems have someone's children at a garden?
4. Imagine you are an ant in a park.
5. What if a cash point would be in the sky?
6. Imagine you are someone's children at a park.
7. How could you sabotage your rivals shop?
8. What would you do <somewhere>?
9. How could you not earn money?
10. Imagine you are a bird next to your shop.
11. Think about you.
12. How could you satisfy your staff's needs?
13. How could you take disadvantage of satisfy your customers needs?
14. What if a teaspoon would be on a coffeecup?
15. Think about your staff.
16. What if a teaspoon would lie at the moon?
17. How could you extend your business?
18. Imagine you are Obi-Wan Kenobi at a garden.
19. What problems have Obi-Wan Kenobi with doing <something>?
20. Think about a cash point.
21. How could your customers sell in the ground?
22. What if a teaspoon would sit on a coffeecup?
23. What would a secretary do <somewhere>?
24. What problems have the pope with doing <something>?
25. How could you earn money?
26. What if a cash point would be next to the ground?
27. What problems have someone's children at your shop?
28. What problems have your grandmother at your shop?
29. How could your staff work at <somewhere>?
30. How could your staff sell in the moon?
31. Think about a desk.
32. Imagine you are under your shop.
33. What if a teaspoon would stay at a garden?

...

C APPENDIX: DEFINITIONS OF ONTOLOGY

Thomas Gruber's definition of an ontology [22], [20]:

- An ontology is an explicit specification of a conceptualization.
- A conceptualization is an abstract, simplified view of the world that we want to represent.
- If the specification medium is a formal language, the ontology defines a representational foundation.

The usual definition that is offered in the context of AI and knowledge representation is the following by Thomas Gruber:

"An ontology is an explicit specification of a conceptualization. The term is borrowed from philosophy, where an Ontology is a systematic account of Existence. For AI systems, what "exists" is that which can be represented. When the knowledge of a domain is represented in a declarative formalism, the set of objects that can be represented is called the universe of discourse. This set of objects, and the describable relationships among them, are reflected in the representational vocabulary with which a knowledge-based program represents knowledge. Thus, in the context of AI, we can describe the ontology of a program by defining a set of representational terms. In such an ontology, definitions associate the names of entities in the universe of discourse (e.g., classes, relations, functions, or other objects) with human-readable text describing what the names mean, and formal axioms that constrain the interpretation and well-formed use of these terms. Formally, an ontology is the statement of a logical theory."

James Geller's definition of ontology [20]:

1. When we say "Ontology" we mean "Computational Ontology." We don't mean philosophical ontology.
2. An Ontology is a graph (the data structure). Every node of this graph stands for a "concept." A concept is a unit that one can think about.
3. Concepts correspond to words or short phrases. Typically, concepts correspond to nouns or noun phrases, but they don't have to. Examples: house, man, car, New York, World Trade Center
4. The nodes of the ontology are connected by different kinds of links. The most important kind of link is called IS-A link.
5. The nodes and IS-A links together form a Rooted Directed Acyclic Graph (Rooted DAG). Rooted means that there is one single "highest node" called the Root. All other nodes are connected by one IS-A link or a chain of several IS-A links to the Root.

6. You know what "directed" means. In our definition, IS-A links point upwards. If an IS-A link points from a concept X to a concept Y that means that every real world thing that can be called an X also can be called a Y. In other words, every X IS-A Y. (Some people have IS-A-like links but pointing downwards.) Examples: A car IS-A vehicle. A dog IS-A animal.

   You will notice this is very similar to an Object-Oriented Database. There we had classes and subclass links. Even the diagrams are similar.

7. Acyclic means that if you start at one node and move away from it following an IS-A link, you can never return to this node, even if you follow many IS-A links.

8. Most nodes also have other information attached. This information includes attributes, relationships and rules (or axioms).

9. An attribute is like a simple string or number variable that contains additional information about that concept. This is very similar to a data member in an Object-Oriented Database or programming language. Examples: An animal can have the attribute "legs" which can have values such as 0, 2, 4, 6, 8. A car can have the attribute color, which can be red, green, etc.

10. A relationship is a link (arrow) that points from one concept to another concept. It expresses how the two concepts relate to each other. Relationships MAY form cycles. The name of a relationship is normally written next to the relationship link. This is very similar to a data member that is a pointer in an Object-Oriented Database or programming language. Example: The concept Car may have a relationship to the concept Person. The name of that relationship could be "Owned."

11. Commonly, IS-A links are also called "IS-A relationships."

12. Other links (relationships) are commonly called "Semantic Relationships." This is to avoid confusion with IS-A relationships.

13. A relationship that connects two concepts is called a binary relationship. Mathematicians allow higher order relationships (ternary, etc.). Most ontologies don't allow higher order relationships. Most approaches have relationships that go in one direction (arrow), but there are double-headed arrows in some models.

14. The IS-A relationship can be used to inherit attributes and semantic relationships down (against the direction of the arrows) from higher nodes to lower nodes in the DAG. This is very similar to inheritance in OODBs and PLs such as C++. Example: If Vehicle has the attribute Price then Car would inherit Price. You don't have to specify that Car has Price.

15. There is some disagreement whether only the attributes are inherited or also the values of attributes. But, IF values are inherited, they may be "overridden" by attributes at lower nodes. Example: I could assign the value "4" to the attribute Legs at the concept

Animal in an ontology. However, the child Bird of Animal could specify the value "2" for "Legs" and this would be the value that is used.

16. Most researchers say that we inherit semantic relationships down. Some ontologies have "blocking mechanisms" to stop inheritance.

17. Higher nodes in the DAG represent general concepts. Lower nodes in the DAG represent specific concepts. Examples: Vehicle is more general than Car. Car is more general than Toyota. Animal is more general than Dog. Dog is more general than Collie.

18. Axioms express universal truths about concepts and are attached to concepts. (We do not use rules or axioms. But many people do.) Example: If X is the husband_of Y, then Y is the wife_of X.

19. It is widely assumed that ontologies represent information in a form that is at least partially similar to how human knowledge is represented.

20. Ontologies represent information in a form that can be used for some forms of reasoning that are at least partially similar to human reasoning. This includes inheritance reasoning, transitivity reasoning and classification. Inheritance was already mentioned before. OODBs do not have transitivity reasoning and do not have classification.

21. Classification means that if we know the attributes of a concept we can decide under which other concepts it belongs in the ontology. Example (simplified): If we know an animal has 4 legs, black stripes, eats meat, runs very fast, and lives in Africa, it must be a tiger.

22. A concept may inherit information from several other concepts. This is called multiple inheritance. Multiple inheritance is important but may cause problems, such as apparent contradictions. Example: (Famous): President Nixon was a Quaker and a Republican. Quakers are considered "peaceful." Republicans are considered "in favor of war." If Nixon inherits from both Quaker and Republican, then, Is he peaceful or in favor of war? (This is called the Nixon Diamond. If you draw it, you see why.)

23. Transitivity reasoning corresponds to chaining of IS-A links. Example: If we know that a Collie IS-A Dog and we also know that a Dog IS-A Animal, then we can conclude that a Collie IS-A Animal.

24. The Rooted DAG is called by some people "taxonomy." It is called by some people hierarchy. Some people call it tangled hierarchy. Some people call it heterarchy.

25. Some people allow an "unrooted" DAG. That means there may be several roots. Most people introduce an artificial root, to make sure that there is a root. Artificial Intelligence people often call this root "Thing." Database people prefer "Entity."

26. Some people allow just a tree instead of a DAG. But trees are very limited in what they can represent. Trees allow no multiple inheritance. Many people say that "hierarchy" may be used only for trees.

27. People say that ontologies store "symbolic" knowledge. They don't mean symbols such as &$%#. They means "words." That means, they mean symbolic as opposed to "numeric." There are knowledge representations that rely on "magic numbers" such as neural networks. Those are not ontologies.

28. Some people use other terms than IS-A. AKO (A kind of) and SUBCLASS are common. Some people call concepts "categories" or "classes" and mean more or less the same with those terms as "concepts."

29. Some people allow Instance-Of links in ontologies. Thus a specific building (Kupfrian) would then be connected to "Building" by an Instance-Of link. Other people don't allow such links. Many people allow them only at the leaf level. Example: In the example above, Nixon is certainly an Instance-Of Republican, not IS-A.

30. So what are the main differences between ontologies and OODBs? Ontologies allow some reasoning, OODBs allow only inheritance. Attached axioms are used for reasoning. Also, as above, reasoning by classfication and transitivity.

31. Secondly, most ontologies do not support instances. They only model classes. Occasionally there are instances at the leaf level. In OODBs most classes have instances. Although there can be virtual (abstract) classes at higher levels in C++.

32. OODBs tend to be better implemented than ontologies.

D APPENDIX: EVALUATION DATA

D.1 IDEAS

IGS 1: Guided Brainstorming

(We, 6.00 p.m.), 5 people, 37 ideas

- Outdoor-Lego
- Wasserringkaempfe
- Tennis mit Ball der Wasser verspritzt
- Frisbeescheibe mit Wasser
- Mensch-Aergere-Dich-Nicht auf grossen Strandtuch mit aufblasbaren Figuren
- Pyramidenbauset (Lehmziegel, Stroh: Baumaterial vorher selber herstellen)
- Nistplatz fuer Tiere (Fledermaeuse/Igel, Hummel, Ameise)
- Sandspielzeug (Rollen, Bahnen, Kugeln, mit Sand erweitern)
- Murmelbauset fuers Zaehneputzen
- Puzzle mit Gutenachtgeschichte (Serie)
- Spielbrett mit Lampe (Eltern koennen Licht ausmachen)
- Verformbare Plastik (erwaermen, verformen, in Form pressen)
- Selber Eis herstellen
- Scherenspielzeug (lustige Dinge schneiden)
- Uhrenbausset
- Musikinstrumente-Bastelset
- Spiele auf Bettlaken
- Spiele auf Bettrahmen
- Webstuhl fuer eigene Stoffe
- Abakus-Bauset
- Murmelbauset fuers Einschlafen (wenn die Murmel unten ist, dann muss ich ins Bett)
- Tatoo-Stift
- Tatoos mit Naturfarben, die wieder abgehen

- Messerset
- Sammelmurmeln ala Pokemon
- ein neuer Stubenhocker/ Campinghocker
- Flugzeug basteln: Holz, Papier, Falten
- Pflanzkasten fuer Sommerblumen + Anleitung
- Solarzellen-Experimentier Set
- optischer Baukasten (Linsen, Spiegel, Prismen)
- Unterwasser-Torpedeo
- Spinnrad mit Wollschaf
- Springbrunnen-Bauset (mit Rohren, Loechern...)
- Uhr mit Holzzahnraedern
- Holzpuzzle mit Stichsaege + Schablonen
- blinkende Murmelbahn, Bilder erscheinen bei Beruehrung mit Murmel
- Feuerset

IGS 2: Association Method

(We, 6.30 p.m.), 4 people, 14 ideas

- Kleckerburgbausatz fuer den Garten
- Radar/ Papier Flugsimulation
- Schneideset/Bastelset: Kiste mit Schneidwerkzeugen, Farben, Papier...
- Gefahren-Elemente-Spiel (Feuer, Wasser, Sand)
- Materialspiel (welches Material ist haerter)
- Murmel-Angeln mit den Zehen (aus verschiedenen Materialien)
- Ausrede/Situations-Kartenspiel (Ausrede und Situation zusammen: Punktevergeabe)
- Ausreden Grund erraten
- Mini-Fussballmatte
- Verkleidungen (Tierkostueme, Beuteltasche: Kanguruh; Ruessel: Elefant)
- Gefahrenelemente-Interaktionsspiel (Feuer loeschen, Ueberschwemmung eindaemmen)
- Gruppenbausatz: jeder baut ein Teil, alle zusammen ein Ganzes
- Robotter

IGS 3: Association Method

(We, 7 p.m.), 3 people, (21 ideas)

- Scheibenjumper (waehrend der Autofahrt)
- Autofahrtspiel: Gegestaende zaehlen, erkennen, raten... Aufmerksamkeitsspiele
- Autokennzeichen Scrabbel
- Sandmalen (mit buntem Sand)
- Spielzeug unter der Decke mit Elternalarm
- Mafia-Automat statt Karten (Spiel findet die Moerder)
- leuchtendes Brettspiel
- Farben als Toene interpretieren (beim Malen erklingt Musik)
- Knete-Brille
- Essbare Kleidung
- Spiel mit Tuer dazwischen (Schwellenspiel)
- Sanduhr zum Spielen
- Apfelleder, aus dem man Gegenstaende herstellen kann, die essbar sind
- Puppen-Pantomieme
- Hau-den-Lukas-Spiel mit Toenen und Farben
- Katapult
- Knete die sich bei Druck verhaertet
- Sand-Stofftier
- Sanduhr + Bauen (Baumeister Bob)
- Logistik-Spielzeug

IGS 4: Kalliope Support

(Th, 12.00 a.m.), 5 people, 29 ideas

- Fussschaufel zum andere Abschiessen (Ball, Sand)
- Schaufelbagger zum Umschnallen
- Schaufelhaende/ Schaufelhandschuh
- Schaufel zum Umschnallen
- gefrorener Boden Schaufeln
- Eiertrudeln

- Ball mit Loechern als portionierbare Wasserbombe
- Pollock-Sandbild-Spiel (mit buntem Sand Bilder werfen)
- bunte Sandburg
- Indoor-Sandkasten
- Buddeln im Wohnzimmer
- Spielgarten im Wohnzimmer: Balkon 1. Etage Balkonrutsche
- Mittelalter-Wohnzimmer
- Puzzle-Tapete
- veraenderbare Tapete
- Klett-Tapete
- Indoor-Drachen
- Malen nach Zahlen
- Wohnzimmer-Garten
- Klangspielzeug fuer Wand/Moebel
- Klangspielzeug fuers Badezimmer
- Material-Tapete: Dart mit Klettbaellen
- Automatik Schaufel, Bagger
- Grassmoebel
- Murmeln am Abhang
- Magnetische Murmeln
- Glasbausteine
- Gedaechtnisspiel: Orte + Farben

IGS 5: Unprepared Brainstorming

(Th 7.00 p.m.), 5 people, 22 ideas

- Schnitzeljagt-Koffer (Kombinationen + Puzzleprinzip)
- mobiles Zelt zum Verstecken
- Verkettbare Springseile
- Strand-Gleitschirme
- farbige Matsche
- modulare Schwimminsel
- Schneekugel mit Klang

- Bude-Bauset (mit Spannmechanismen, innen und aussen-geeignet)
- Transformer-Spielzeug (zusammenbaubar und kombinierbar)
- Verstecken-Spiel-Spielzeug
- flexibel Stoff mit Kunststoffstreifen (mit einer Hand aufbaubar)
- Musikinstrument mit Wasser betrieben
- Liederspielmatte (Melodien durch rumspringen)
- Trampolinparcours
- multifunktions Holzringe
- Geraeusche-Raten-Koffer
- Kugellabyrinth und Drehscheibe und Zylindern (als Teamspiel): Zylinder schieben, Kugel im Labyrinth
- Entdeckungskoffer (Lupe, Pinzette...) fuer die Reise
- zusammenpuzzlebare Landkarte fuer Schnipseljagt
- Schnips-Spiel: Box mit verschiedenen Elementen, Geschicklichkeit, Box mitnehmbar
- Jonglierlernspiel

IGS 6: Guided Brainstorming

(Th 6.00 p.m.), 5 people, 20 ideas

- Floss zum Selberbauen aus grossen Plastikbauteilen
- Federschuhe/ gefederte Laufgeraete
- Stoecker-Baukasten
- Wurfgeraete mit Geraeuschen (Bola)
- Geraeusch-Wurf-Geschoss (Frisbee, Ball)
- Kanalbausystem fuer den Strand
- Lego fuer draussen, Steine mit Metallkern, mit Magnet einsammelbar)
- Schwimminsel zum Zusammenbauen
- modulares Hamsterlabyrith zum Selberbauen
- Luftballonset zum immer wieder neue Tiere und Dinge formane, mit Anleitung und speziell geformten Luftballons
- formbarer Knautschsack
- grosser Knautschball (Hackysack im Grossformat)
- Abschussrampe Flugzeuge etc.

- Riesenmikado
- Geraeusche-Aufgaben Spiel
- Wassermuehle-Bauset
- Drachenbaukasten
- Sammlerset (verschiedenartige Gegenstaende, Figuren + Karten)

IGS 7: Kalliope Support

(Thu, 12.00 p.m.), 5 people, 39 ideas

- kluge Schaufel, sagt was sie ausgraebt
- Kreideroller: Roller malt mit Kreide auf die Strasse
- sprechende Schaufel
- flexible Schaufeln
- Huepfschaufeln: im Sand schaufeln, auf Beton springen
- wachsende Schaufeln
- Unterwasserbaelle
- Wasserpantoffeln
- Um-Die-Ecke-Schaufel
- essbares Wohnzimmer
- Puzzle-Wohnzimmer
- Zapping-Spiel
- lebendige Stifte
- Stift mit Motor
- selbst-schreibende Stifte
- Hohler Dildo fuer Stifte
- Fernangeln mit Fernbedienung aus dem Zimmer
- Puzzle zum Backen
- Spielzeugteigmischung zum Selberbacken
- erweiterbare Spielzeugbackmischung (vgl Herrmann)
- nachwachsende Spielzeuge vom Gummibaum
- Gummibaumsaft fliesst in Spielzeugform
- Wohnzimmer als Tier das frisst und pupst
- Holzoma/Holzopa als Puppen

- Tierspuren-Stempelschuhe
- Stempelschuhe fuer Hunde/Tiere
- Holz-Dildo
- Fleischmurmeln
- Heliumspielzeug
- Murmeln mit eingeschlossenen Viren
- eckige Murmeln auf Raedern
- Murmeln mit Raedern
- blinkende Murmeln
- Geraeusch-Murmeln
- Murmelwaehrung
- Schnitzwerkzeug fuer Murmeln
- Murmeln zum in die Ohren und in die Nase stecken (ohne Folgeschaeden)

IGS 8: unprepared Brainstorming

(Thu 7.00 p.m.), 5 people, 8 ideas

- Beachtennis
- Ballspielzeug: schwerer Gegenstand in der Mitte, ein oder mehrere Baelle an Baendern drumherum, Schlaeger
- Drachen fuer Zuhause
- leuchtende Murmeln
- Murmelbahnen aus Papier/Pappe zum Basteln
- Turmbau mit Bechern und Baelle zum Werfen
- Becher-Bau-Spielzeug: Turm aus Bechern bauen, mit Bechern Turme kaputtwerfen... (Regelspiel)
- Sammelkarten + Figuren

D.2 EVALUATION OF IDEAS

The ideas generated in the IGSs were assessed regarding quality criteria: 'understandable', 'interesting', 'innovative', 'appropriate to the task' and 'possible to implement'. Each idea could get maximum five points for every of these criteria.

Idee	verstaendlich	interessant	passt zur Aufgabe	innovativ	realisierbar	Session Id
Bude-Bauset (mit Spannmechanismen, innen und aussen-geeignet)	3	2	2	2	2	5
Entdeckungskoffer (Lupe, Pinzette...) fuer die Reise	5	5	4	1	4	5
farbige Matsche	4	4	3	2	3	5
flexibel Stoff mit Kunststoffstreifen (mit einer Hand aufbaubar)		1	1	1	1	5
Gerausche-Raten-Koffer	4	3	4	1	3	5
Jonglierlernspiel	5	4	4	2	5	5
Kugellabyrinth und Drehscheibe und Zylindern (als Teamspiel): Zylinder schieben, Kugel im Labyrinth	3	4	4	2	3	5
Liederspielmatte (Melodien durch rumspringen)	4	4	4	2	2	5
mobiles Zelt zum Verstecken	4	3	2	2	2	5
modulare Schwimminsel	3	4	2	1	2	5
multifunktions Holzringe	3	1	2	1	2	5
Musikinstrument mit Wasser betrieben	4	4	3	4	2	5
Schneekugel mit Klang	2	1		1	2	5
Schnips-Spiel: Box mit verschiedenen Elementen, Geschicklichkeit, Box mitnehmbar	3	3	3	1	3	5
Schnitzeljagt-Koffer (Kombinationen + Puzzleprinzip)	3	2	3	2	3	5
Strand-Gleitschirme	4	4	1	1	2	5
Trampolinparcours	3	3			1	5
Transformer-Spielzeug (zusammenbaubar und kombinierbar)	4	3	2		2	5
Verkettbare Springseile	5	2	2	2	3	5
Verstecken-Spiel-Spielzeug	2	1	1			5
zusammenpuzzlebare Landkarte fuer Schnipseljagt	5	5	3		4	5

Figure 20. quality assessment IGS 5: unprepared unguided brainstorming

Idee	verstaendlich	interessant	passt zur Aufgabe	innovativ	realisierbar	Session Id
Ballspielzeug: schwerer Gegenstand in der Mitte, ein oder mehrere Baelle an Baendern drumherum, Schlaeger	3	2	3	1	1	8
Beachtennis	5	2	4		4	8
Becher-Bau-Spielzeug: Turm aus Bechern bauen, mit Bechern Turme kaputtwerfen... (Regelspiel)	5	4	4	2	5	8
Drachen fuer Zuhause	2	2	2		2	8
leuchtende Murmeln	5	3	3	1	4	8
Murmelbahnen aus Papier/Pappe zum Basteln	4	3	4	2	4	8
Sammelkarten + Figuren	5	2	2		3	8
Turmbau mit Bechern + Baelle zum Werfen	5	1	3		4	8

Figure 21. quality assessment IGS 8: unprepared unguided brainstorming

Idee	verstaendlich	interessant	passt zur Aufgabe	innovativ	realisierbar	Session Id
Abakus-Bauset	1	1	1		1	1
blinkende Murmelbahn, Bilder erscheinen bei Beruehrung mit Murmel	4	2	1	1	1	1
ein neuer Stubenhocker/ Campinghocker	3			1	1	1
Feuerset	5	3	2	3	3	1
Flugzeug basteln: Holz, Papier, Falten	5	5	5	1	4	1
Frisbeescheibe mit Wasser	2	2	2	2	1	1
Holzpuzzle mit Stichsaege + Schablonen	5	4	2	1	3	1
Mensch-Aergere-Dich-Nicht auf grossen Strandtuch mit aufblasbaren Figuren	5	4	4	3	4	1
Messerset	5				1	1
Murmelbauset fuers Einschlafen (wenn die Murmel unten ist, dann muss ich ins Bett)	4	2	1	2	2	1
Murmelbauset fuers Zaehneputzen	3	1	1	2	2	1
Musikinstrumente-Bastelset	5	5	3	3	3	1
Nistplatz fuer Tiere (Fledermaeuse/Igel, Hummel, Ameise)	4	3	3	1	1	1
optischer Baukasten (Linsen, Spiegel, Prismen)	5	5	3	1	2	1
Outdoor-Lego	4	3	3			1
Pflanzkasten fuer Sommerblumen + Anleitung	5	3	1		1	1
Puzzle mit Gutenachtgeschichte (Serie)	4	2	1		1	1
Pyramidenbauset (Lehmziegel, Stroh: Baumaterial vorher selber herstellen)	4	4	2	3	1	1
Sammelmurmeln ala Pokemon	5	1	2		2	1
Sandspielzeug (Rollen, Bahnen, Kugeln, mit Sand erweitern)	4	3	3	2	3	1
Scherenspielzeug (lustige Dinge schneiden)	4		1	1	1	1
Selber Eis herstellen	5	5	2	1	1	1
Solarzellen-Experimentier Set	5	5	3	2	2	1
Spielbrett mit Lampe (Eltern koennen Licht ausmachen)	2	1			1	1
Spiele auf Bettlaken	4	3	3	2	3	1
Spiele auf Bettrahmen	3	2	1		1	1
Spinnrad mit Wollschaf	3	1	2	1	2	1
Springbrunnen-Bauset (mit Rohren, Loechern...)	5	5	2	4	3	1
Tatoos mit Naturfarben, die wieder abgehen	3	3	3	2	3	1
Tatoo-Stift	5	4	3		3	1
Tennis mit Ball der Wasser verspritzt	4	3	3	3	3	1
Uhr mit Holzzahnraedern	4	2	2	2		1
Uhrenbausset	5	4	2	3	1	1
Unterwasser-Torpedeo	4	4	2	2		1
Verformbare Plastik (erwaermen:verformen, in Form pressen)	5	4	3	2	2	1
Wasserringkaempfe	4	3	1		1	1
Webstuhl fuer eigene Stoffe	5	3	3	2	2	1

Figure 22. quality assessment IGS 1: guided brainstorming

Idee	verstaendlich	interessant	passt zur Aufgabe	innovativ	realisierbar	Session Id
Abschussrampe fuer Flugzeuge etc	5	2	4	2	4	6
Drachenbaukasten	5	5	3	4	4	6
Federschuhe/ gefederte Laufgeraete	5	5	4	1	3	6
Floss zum Selberbauen aus grossen Plastikbauteilen	5	5	3	4	2	6
formbarer Knautschsack	5	2	5		4	6
Geraeusche-Aufgaben Spiel	5	5	4	2	4	6
Geraeusch-Wurf-Geschoss (Frisbee, Ball)	5	3	3	1	4	6
grosser Knautschball (Hackysack im Grossformat)	4	4	3	1	3	6
Kanalbausystem fuer den Strand	5	4	3	4	3	6
Lego fuer draussen, Steine mit Metallkern, mit Magnet einsammelnbar)	5	5	4	2	2	6
Luftballonset zum immer wieder neue Tiere und Dinge formen, mit Anleitung und speziell geformten Luftballons	4	4	3	3	3	6
modulares Hamsterlabyrith zum Selberbauen	5	4	4	3	4	6
Riesenmikado	5	2	4	2	4	6
Sammlerset (verschiedenartige Gegenstaende, Figuren + Karten)	5	1	2		2	6
Schwimminsel zum zusammenbauen	3	3	3	2	3	6
Stoecker-Baukasten						6
Wassermuehle-Bauset	5	5	3	4	3	6
Wurfgeraete mit Geraeuschen (Bola)	5	3	3	3	3	6

Figure 23. quality assessment IGS 6: guided brainstorming

Idee	verstaendlich	interessant	passt zur Aufgabe	innovativ	realisierbar	Session Id
Ausrede/Situations-Kartenspiel (Ausrede und Situation zusammen: Punktevergeabe)	5	4	3	3	4	2
Ausreden Grund erraten	3	1	2	2	2	2
Gefahrenelemente-Interaktionsspiel (Feuer loeschen, Ueberschwemmung eindaemmen)	5	5	4	2	3	2
Gefahren-Elemente-Spiel (Feuer, Wasser, Sand)	4	4	4	2	4	2
Gruppenbausatz: jeder baut ein Teil, alle zusammen ein Ganzes	5	5	4	5	4	2
Kleckerburgbausatz fuer den Garten	5	4	5	3	5	2
Materialspiel (welches Material ist haerter)	5	4	3	3	4	2
Mini-Fussballmatte	4	1	2		2	2
Murmel-Angeln mit den Zehen (aus verschiedenen Materialien heraus)	3	1	1	2	1	2
Radar/ Papier Flugsimulation						2
Robotter	5	4	1			2
Schneideset/Bastelset: Kiste mit Schneidwerkzeugen, Farben, Papier...	5	4	1		2	2
Verkleidungen (Tierkostueme, Beuteltasche: Kanguruh Ruessel: Elefant)	5	5	3	1	3	2

Figure 24. quality assessment IGS 2: guided association technique

Idee	verstaendlich	interessant	passt zur Aufgabe	innovativ	realisierbar	Session Id
Apfelleder, aus dem man Gegenstaende herstellen Kann, die dann auch essbar sind	4	3	1	4		3
Autofahrtspiel: Gegestaende zaehlen, erkennen, raten... Aufmerksamkeitsspiele	5	3	1	2	4	3
Autokennzeichen Scrabbel	5	2	3	2	5	3
Essbare Kleidung	4	3			1	3
Farben als Toene interpretieren (beim Malen erklingt Musik)	4	3	3	3	4	3
Hau-den-Lukas-Spiel mit Toenen und Farben	5	4	2	2	2	3
Katapult	5	5	4	1	4	3
Knete die sich bei Druck verhaertet	3			1	1	3
Knete-Brille	2				1	3
leuchtendes Brettspiel	5	3	4	2	4	3
Logistik-Spielzeug						3
Mafia-Automat statt Karten (Spiel findet die Moerder)	1			1		3
Puppen-Pantomieme	2	1	1	1	1	3
Sandmalen (mit buntem Sand)	5	3	2	1	2	3
Sand-Stofftier	3	1	2		2	3
Sanduhr + Bauen (Baumeister Bob)	5	5	3	2	2	3
Sanduhr zum Spielen	5	1	2	1	2	3
Scheibenjumper (waehrend der Autofahrt)	1		1		1	3
Spiel mit Tuer dazwischen (Schwellenspiel)						3
Spielzeug unter der Decke mit Elternalarm	1	1	1	1		3

Figure 25. quality assessment IGS 3: guided association technique

Idee	verstaendlich	interessant	passt zur Aufgabe	innovativ	realisierbar	Session Id
Automatik Schaufel, Bagger	4	2	3	1	1	4
Ball mit Loechern als portionierbare Wasserbombe		1	1	1	1	4
Buddeln im Wohnzimmer	2	1	1	1	1	4
bunte Sandburg	3	2	2	1	2	4
Eiertrudeln	5	2	3		3	4
Fussschaufel zum andere Abschiessen (Ball, Sand)	2		1	1	2	4
Gedaechtnisspiel: Orte + Farben	4	3	2		3	4
gefrorener-Boden Schaufeln	1	1				4
Glasbausteine	4	3	2	3	2	4
Grassmoebel	2	1		1	1	4
Indoor-Drachen	3	2	2	2	1	4
Indoor-Sandkasten	4	2	2	3	1	4
Klangspielzeug fuer Wand/Moebel	3	3	2	2	2	4
Klangspielzeug fuers Badezimmer	2	2	2	1	2	4
Klett-Tapete	4	3	1	3	1	4
Magnetische Murmeln	5	3	2		3	4
Malen nach Zahlen	5	2	2		3	4
Material-Tapete: Dart mit Klettbaellen	4	3	3	2	3	4
Mittelalter-Wohnzimmer						4
Murmeln am Abhang	3					4
Pollock-Sandbild-Spiel (mit buntem Sand Bilder werfen)	1	1	1		1	4
Puzzle-Tapete	4	1	3	3	3	4
Schaufel zum Umschnallen	2		1		1	4
Schaufelbagger zum Umschnallen	2	1	2	1	2	4
Schaufelhaende/ Schaufelhandschuh	3	3	3	3	3	4
Spielgarten im Wohnzimmer: Balkon 1. Etage Balkonrutsche	3	3		3		4
veraenderbare Tapete	2	1	1	2	1	4
Wohnzimmer-Garten	2	1		1	2	4

Figure 26. quality assessment IGS 4: kalliope support

Idee	verstaendlich	interessant	passt zur Aufgabe	innovativ	realisierbar	Session Id
blinkende Murmeln	5	2	2	1	4	7
eckige Murmeln auf Raedern	1	1	1	1	1	7
erweiterbare Spielzeugbackmischung (vgl Herrmann)	4	3	3	2	4	7
essbares Wohnzimmer	3	2		1	1	7
Fernangeln mit Fernbedienung aus dem Zimmer	4	2	2	3	1	7
Fleischmurmeln	2			1	1	7
flexible Schaufeln	2	1	1	1	1	7
Geraeusch-Murmeln	2	2	2	1	2	7
Gummibaumsaft fliesst in Spielzeugform	2	3	1	3	1	7
Heliumspielzeug	4	4	2	4	2	7
Hohler Dildo fuer Stifte	2				1	7
Holz-Dildo	3				2	7
Holzoma/Holzopa als Puppen	5	1	2	1	3	7
Huepfschaufeln: im Sand schaufeln, auf Beton springen	2	3	2	3	1	7
kluge Schaufel, sagt was sie ausgraebt	4	1	1	3	1	7
Kreideroller: Roller malt mit Kreide auf die Strasse	3	2	2	3	1	7
lebendige Stifte	1	2	2	1	1	7
Murmeln mit eingeschlossenen Viren	2					7
Murmeln mit Raedern	2		2		1	7
Murmeln zum in die Ohren und in die Nase stecken (ohne Folgeschaeden)	3	1	1	2	1	7
Murmelwaehrung	1		1		1	7
nachwachsende Spielzeuge vom Gummibaum	2	1		1		7
Puzzle zum Backen	1	1	1	1	1	7
Puzzle-Wohnzimmer	2	1	1		1	7
Schnitzwerkzeug feur Murmeln	2	1				7
selbst-schreibende Stifte	3					7
Spielzeugteigmischung zum Selberbacken	3			1	1	7
sprechende Schaufel	4	2	1	2		7
Stempelschuhe fuer Hunde/Tiere	3	1	2	3	1	7
Stift mit Motor	1			1		7
Tierspuren-Stempelschuhe	3	2	3	2	3	7
Um-Die-Ecke-Schaufel	1					7
Unterwasserbaelle	2	2	2	2	1	7
wachsende Schaufeln						7
Wasserpantoffeln	1			1		7
Wohnzimmer als Tier das frisst und pupst						7
Zapping-Spiel	1					7

Figure 27. quality assessment IGS 7: kalliope support

GLOSSARY

Notation	Description	
abstraction_of	The relation between a concept and a set of other concepts that all have the properties of the abstract concept in common.	34
akin_to	The relation between two concepts which are connected in the lattice of concepts.	34
algorithm	A prescription of a mechanical process that takes place without a need for interpretation.	2
attribute	A property of a concept. By means of attributes a concept can be explained and communicated.	31
average value	A measure of the numerical data in a dataset. $\mu = \frac{\sum_{i=1}^{n} X_i}{n}$	67
class	A set of objects, with all objects being a subset of objects of their kind, having a specific classifying attribute in common.	26
concept	An object of the real world or the world of thoughts.	31
control point	A specific concept of the ontology that is used as navigation point to apply restructuring strategies to. Usually a set of central concepts of the current problem domain is selected by the user, which become control points.	49
creativity	The ability to produce work that is both novel (that is, original and unexpected) and appropriate (that is, useful, adaptive concerning task constraints) [31].	6
creativity techniques	Heuristic methods to facilitate creativity in a person or group of people [12].	8
database	A structured collection of records of data that is stored in a computer so that a program can consult it to answer queries. [13]	53

Notation	Description	
design	Taking justifiable and conscious decisions for the future benefit of one or more identified stakeholders [47]	3
directed graph	A 2-tuple G=(V,E) as follows: V is the set of elements, called vertices; E is the set of ordered pairs of vertices, called edges [14].	26
domain	The relation between an attribute and the set of concepts, where this attribute can be applied to.	32
fact	The relation between a concept, an attribute from the concept's `signature` and a value that can be assumed to this variable.	32
grammar	A 4-tuple $G = (V, \Sigma, P, S)$: V is the finite set of variables (nonterminals); Σ is the finite set of the alphabet of terminals: $V \cap \Sigma = \emptyset$; P is a finite set of productions, it is a finite subset of $(V \cup \Sigma)^{+} \times (V \cup \Sigma)^{*}$; $S \in V$ is the start variable[34] .	22
Hamming distance	A measure of the difference between items regarding attributes and values of these attributes.	35
idea	A new thought of a person. An idea is not necessarily a solution for the design task, it can be unrealistic or inappropriate, but it can lead to a solution for the problem.	3
idea engineering	An engineering approach to create ideas professionally (reliable, repeatable, possible to plan and to maintain).	14
inspiration	An event that initializes the process of having a person producing innovative ideas. Any material object that can be perceived or immaterial object that can be thought of, is a potential source of inspiration. Whether it actually inspires somebody, depends on the person's attitude and abilities.	3
knowledge base	A special kind of database for knowledge management, it provides the means for the computerized collection, organization, and retrieval of knowledge[15]	36

Notation	Description	
lattice	A partially ordered set that is: a set where an ordering relation exists between the elements of some of the pairs, but not necessarily for all the pairs.	33
ontology	An explicit specification of a conceptualization[22]. A conceptualization is an abstract, simplified view of the world that I want to represent, containing a description of the concepts of the world and relationships between those concepts.	25
opposite_of	The relation between two opposing values with respect to a specific attribute.	33
problem distance	A distance between concepts that is used for navigation during restructuring. The problem distance is the number of `fact` relations + `value_is_concept` relations to reach a concept from another.	49
problem owner	A person, who has a problem and needs to solve this.	1
quality of ideas	A subjective criterion for evaluating ideas according to appropriateness and novelty. The quality of ideas can be only decided by the owner and stakeholders of the problem.	61
quantity of ideas	The amount of ideas generated in an IGS.	61
range	The relation between an attribute and the set of values that can be assumed to this attribute.	32
signature	The relation between a concept and the set of attributes that describe the concept.	32
similar_to	The relation between two concepts which have a set of attributes and values according to this attributes in common.	35
specialization_of	The relation between a concept and a set of other concepts, where the first concept contains the `signature` of the second concepts, and all facts of the first concept regarding attributes of the abstract concept's signature are contained in the second concept.	33

Notation	Description	
stakeholder	A person who is affected by any consequence of the proposed idea made in a design process, in example users, customers, sponsors, and maybe also technicians and designers of the design process[26].	3
standard deviation	A measure of the spread of data in a dataset. $$\sigma = \sqrt{\frac{\sum_{i=1}^{n}(X_i - \bar{X})^2}{(n-1)}}$$	67
value	The current information contents of a variable.	31
value_is_concept	The relation that expresses that a value and a concept refer to the same thing.	33
variable	A concept together with an attribute forms a variable, which can assume a value.	31
variety of ideas	An objective quality criterion for evaluating ideas that is a measure of the difference of ideas regarding attributes and assumed values. The variety is calculated using the Hamming distance.	61
variety of ideas	The difference of ideas regarding characteristics.	3

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DECLARATION

I declare that this thesis has been composed by myself, that the work contained herein is my own except where explicitly stated otherwise in the text, and that this work has not been submitted for any other degree or professional qualification except as specified.

Technische Universiteit Eindhoven, December 2006 - September 2007

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