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**Cognitive Styles in the Creative Process :
utilization of prior knowledge and experiences**



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Cognitive Styles in the Creative Process : utilization of prior knowledge and experiences

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ABSTRACT

This research aims at understanding the creative process of product designers in terms of exploration and utilization of prior knowledge. A protocol study was conducted with 24 master students who majored in industrial design. For the design experiment, two different design briefs were utilized to investigate the effect of constraints on the creative process. 24 verbal protocols were firstly segmented into think flows, and then encoded. The encoding results suggested the significant effect of constraints on the utilization of precedents. For further interpretation of verbal protocols, I devised a new way of representing the cognitive process – a cognitive map. A cognitive map visualized the entire cognitive activities of participants, and provided a comprehensive view of a cognitive process. The cognitive maps suggested three phases of the creative process – exploration, generation, and development. Each phase represented different cognitive activities which were related to the exploration of precedents and generation of ideas. The cognitive styles of each phase were defined, and integrated. As a result, four different cognitive styles were identified – *Focused Probers*, *Treasure Hunters*, *Selectors*, and *Explorers*. The differences among the styles were compared in terms of utilization of prior knowledge, and the results showed that non-significant differences among four cognitive styles. Finally, this paper concluded with a discussion about implications on design education and practice.

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INTRODUCTION

Prior knowledge and experiences have been regarded as a critical component of a creative thinking process aimed at the creation of the new (Hyman, 1961; Runco & Chand, 1995; Ward, 1995). In the design process which also requires creative thinking, prior knowledge and experiences play a pivotal role. Laxton (1969) mentions a reservoir of knowledge as prerequisite for design ability. In their protocol study, Suwa and Tversky (1997) have found that background knowledge, especially the domain knowledge, make a significant contribution to and has implications for designing.

Domain knowledge in the field of design has often been represented as precedents. As Goldschmidt (1998) clearly stated, the role of precedents in design is quite different from precedents in the practice of law, which provides identical cases to adopt. On the other hand, the design precedents rather support the design activities as reference. Designers could refer to their pool of precedents in order to find problem solving elements which can be reused in a different design problem (Visser & Trousse, 1993). Addition to the solution generation phase, designers also utilize their episodic knowledge to understand the problem, and evaluate their solutions (Visser, 1995).

In Lawson's elaborated explanation of design expertise (2004a), precedents help designers to form their own schemata and also are utilized as gambits to recognize the design situation. Even in students group, the development of expertise changes the ways precedents are used, from

geometric referencing to symbolic one. This also suggests that precedents are actively engaged in not only the design process but also the development of design expertise.

The level of dependency on prior knowledge and experiences may vary depending on designers. For example, the study by Kruger and Cross (2006) empirically shows that some designers often utilize their prior knowledge rather than other sources. They named this type of design strategy as knowledge driven design. The results of previous studies show that prior knowledge and experiences contribute to designing throughout the whole design process. As such, the utilization of such knowledge has the potential to be developed into a design strategy (Kruger & Cross, 2006).

Although many studies have expanded our understanding of how prior knowledge and experiences inform design activity, prior knowledge and experiences were comparatively treated as less critical elements in the investigation of designers' cognitive process. Sometimes their utilization and contribution were identified incidentally while researchers investigated other aspects of cognitive process or design, such as design expertise (Lawson, 2004a) and design reuse (Visser, 1995). Even in the few studies which have focused on prior knowledge and experience themselves, authors have taken the perspective of memory organization in order to investigate the contribution of prior knowledge to designing (R. Oxman, 1990; R. E. Oxman, 1994).

This research investigates the cognitive process of designers in terms of utilizing prior knowledge and experience in order to explore its implication on the cognitive styles and idea generation ability. I devise a new mean to visualize the cognitive process in order to interpret and analyze it. Details of this method will be described later. In cases of previous protocol studies, charts or graphs which display the frequencies of each encoded item along the time frame are one of the most popular methods to represent the results (Akin & Lin, 1995;

Eckersley, 1988; Suwa, Purcell, & Gero, 1998). There are other methods to display the coding results such as providing excerpts from the protocol and statistic tables, but still the representations are limited (Eastman, 1968; Goldschmidt, 1991; Schon & Wiggins, 1992; Suwa, et al., 1998). The new display devised in this study suggests a novel and comprehensive way to understand and present coded protocol data.

The domain of the current design research ranges over architecture (Schon & Wiggins, 1992), interior design (Eckersley, 1988), engineering design (Atman, et al., 2007), industrial design (Dorst & Cross, 2001), and electronic design (Gero & Mc Neill, 1998). There are several studies which recruit participants from a variety of design discipline (Atman, et al., 2007; Eastman, 1968). However, this research focused on a single domain – industrial design, especially the product design discipline.

The following section begins with a detailed account of experimental design and procedure, including the coding strategy and the coding scheme used in this study. Next, the visualization method of protocols and the outcomes are presented within a theoretical, analytical framework. The results section is composed of two parts. In the first, findings from the encoded protocols are discussed through statistical analysis. The results are compared with previous studies. Findings are then, generalized. A second section provides a more specific, detailed description of designers' cognitive processes using the graphical representations of the protocols. Different cognitive styles in the creative process are introduced together with their characteristics. This paper concludes with a discussion of relevant issues for implication and further studies.

LITERATURE REVIEW

1 The known to the new

Previous studies in cognitive psychology support the significant role of prior knowledge and experiences in creative thinking. Conceptual expansion which was proposed by Ward et al. (1997) is an example of how prior knowledge may influence the creative process. It refers to a cognitive activity whereby peoples' knowledge of familiar concepts is extended for creating, even to different domains. Other researchers have proposed the conceptual combination and reorganization as a significant ability of human creativity (Baughman & Mumford, 1995; Mumford, Mobley, Reiter-Palmon, Uhlman, & Doares, 1991; G. M. Scott, Lonergan, & Mumford, 2005). These studies support the contribution of existing knowledge and experiences in creative process.

However some studies have argued that prior experiences can inhibit the creative process. An experimental result showed that people created something highly resembled the properties of existing animals even though they were asked to design an alien creature (Ward, 1994). Similarly, it has been suggested that providing examples may constrain the novelty of ideas

though the number of generated ideas remained uninfluenced (Smith, Ward, & Schumacher, 1993).

1.1 Prior knowledge and experiences in design

In the design discipline, prior knowledge and experiences have been frequently viewed as precedents which are defined as either whole or parts of past designs that designers are aware of (Lawson, 2004b; Pasman, 2003). Precedents provide relevant solutions or ways of designing that designers can refer to. For example, in the discipline of fashion design, designers are often heavily influenced by recent trend, especially the aesthetic style and form. Textile designers actively utilize previous designs as well as other sources of inspiration to generate new ideas and communicate with others (Eckert & Stacey, 2000). Architects have made extensive use of pattern books which contain accumulated knowledge related to architectural styles and details (Lawson, 2006). Industrial designers acquire and apply relevant knowledge from precedents while they creating the form of a design concept (Muller & Pasman, 1996).

A set of promising creative processes suggested by Gero (2000) also illustrated the way precedents contribute to designing. Especially the process of combination and transformation (or mutation) described as the creative process as manipulation of previous designs. The process of analogy also required a prior knowledge or information to refer to (Cross, 1997). The description of Lawson (2004b) demonstrated how precedents influence various aspects of design based on the model of design constraints. The great use of historical styles and referring of its aesthetical details may constrain the formal aspect of design, and at times also constrain the symbolic aspect. In terms of a generator which may then define constraints, a designer can

constrain his or her design when s/he tries to construct one's signature style throughout every designed entity.

Lawson's explanation provided a further aspect of precedent utilization, which may reduce the novelty or innovativeness of an idea. Jansson and Smith (1991) had found that even the professional mechanical engineers appeared to become 'fixated' on the existing solution provided in advance. Successive studies conducted by a group of researchers (A. Purcell, Williams, Gero, & Colbron, 1993; A. T. Purcell & Gero, 1992, 1996) reported the fixation in both of mechanical designers and industrial designers, though the degree of fixating was different across the disciplines.

1.2 Organization of design knowledge

Although many researches have mentioned great use of precedents, designers also refer to general knowledge and experiences beyond the design discipline (Eilouti, 2009; Gonçalves, Cardoso, & Badke-Schaub, 2014; Lawson, 2005). For some, there has been a tendency to regard design as a process of manipulating the knowledge of prior experiences in order to adapt to current problems (R. Oxman, 1990; Schön, 1988). The result of an empirical study also displayed utilization of comprehensive knowledge, including the knowledge of indirect experiences obtained through others' experience (Visser, 1995).

Then, how is these prior experiences and knowledge employed in the design activity? According to Oxman (1990), the adaptation of prior experiences to design is highly depending on the structure and organization of knowledge in the memory system. Designers usually obtain

design knowledge from episodic experiences. When these episodic experiences are stored in the memory system, a generalization process accompanies the abstraction of specific details of experiences. Oxman (1990) elaborated the generalization process of designers as *typification*, which involves classification of experiences depending on typical types of situations, constraints and goals. This depicts how semantic memory can be constructed through episodic memory. Typification also supports indexing of particular experience. Episodic experiences are memorized in association with typified concepts. These concepts become indices which help designers to explore and retrieve relevant knowledge which may then be applied to support an understanding of the current design problem.

Although Oxman (1990) has suggested the role of prior knowledge in the design process, the theory was underpinned by an understanding of the memory system not from the cognitive process itself. In this regard, this research focuses upon the role of different precedents in the creative process by examining the cognitive activities of designers. This then has implications for our understanding of the ways designers utilize existing knowledge depending on design problems, and how these ways can be used to differentiate designers in terms of their cognitive styles.

METHOD

2 Experimental design

2.1 Participants

A total 24 Masters students in the industrial design field participated in the experiment. All of them had studied in an industrial design department or a product design department for their undergraduate degree. Thirteen participants were female, and eleven were male. The average age of the participants was 24.8; ages ranged from 22 to 29. In terms of their experience, two had professional experiences in the product design field for 1~1.5 year, and one participant had worked in an interior design firm for 4 month. According to Lawson (2004a), design expertise requires a certain amount of experience –approximately 8 years in the case of architecture – to mature. In this regard, three participants have relatively little experience to classify them as a professional group. The primary analysis which compared the encoded protocols of these three participants with others also suggested that their experience had less or no impact on their design activities. Thus it could be concluded that the participants were nearly homogeneous in terms of their level of expertise in the design discipline.

2.2 Design briefs with different constraints

Each participant received a design brief in written form. The brief used in this study was related to an ordinary product which has simple functionality – a folding chair. A chair was intentionally chosen, because most people have prior experiences related to it generally. This could facilitate utilization of prior knowledge and experiences to generate and develop design ideas.

Instead of giving the same brief to all participants, two slightly different design briefs were utilized as listed below.

Design brief 1: Design a folding chair

Design brief 2: Design a folding chair for 20-30s who live alone in a small size flat.

Both design briefs are open-ended and have no specific requirements related to the output of design exercise. Such freedom was given to observe the most natural and intrinsic cognitive activities of participants while they generate ideas and develop them. Participants were allowed to generate solutions which satisfy the design brief based on their understanding. The number of ideas and the level of detail of any final outputs were also not specified either.

2.2.1 The Influence of constraints on the cognitive process

Two different design briefs were devised based on the assumption that the cognitive process of the participants may change depending on the constraints that designers deal with. In order to propose this hypothesis, the results of several studies were reviewed which have discussed the role and influence of constraints on cognitive activities.

Design constraints may be described as specifications which define what the design should satisfy or should not be (M. Gross & Fleisher, 1984; Onarheim, 2012). Some constraints are clearly defined and suggested while others are less binding and ambiguous. From the viewpoint of constraints, many researchers portray the design process as a process of managing constraints (Bonnardel, 2000; Chandrasekaran, 1990; Gero, 1990; M. D. Gross, Ervin, Anderson, & Fleisher, 1988; Toye, Cutkosky, Leifer, Tenenbaum, & Glicksman, 1994). In the “Geneplore model” suggested by Ward et al (Ward, Smith, & Finke, 1999), constraints were described as an important part of the design process. During a process of design, the prescribed constraints assist designers in the construction of additional constraints proposed by themselves (Chandrasekaran, 1990). Moreover, Chevalier & Ivory’s (2003) study showed that the constraints provided by clients have a stronger influence upon the cognitive activities of designers. Although there is no apparent consensus about the effect of constraints whether they inhibit or promote creativity (Noguchi, 1999; Smith, et al., 1993), many researches supports the significant influence of constraints on the cognitive process.

2.2.2 Differences between two design briefs

Although the constraints of the two design briefs were suggested by the researchers, each brief embraced different domains. The design brief 1 only defines the product category and its functionality which is susceptible to greater interpretation. The second brief additionally constrains the target users of the product and the place where it will be placed and utilized.

The domain of constraints can be explained clearly by the model of design constraints suggested by Lawson (2005). In his model of design constraints, Lawson suggested three dimensions, defined as the generators, domains and functions of constraints. In terms of the generators, the

researchers play the role of clients who require design concepts of a folding chair. This constrains the radical aspect of the product – fundamental functions as a chair – and the internal features which are related to the product itself. The differences between brief 1 and 2 are additional constraints that brief 2 only holds. Because the brief 2 provides the specific place that a chair will be used, it has an external constraint to be considered. The age range of target users also affect to the product design itself which means the internal aspect, and the external context and environment the product will be places and utilized. Figure 1 illustrates the constraints that brief 1 and 2 possess respectively.

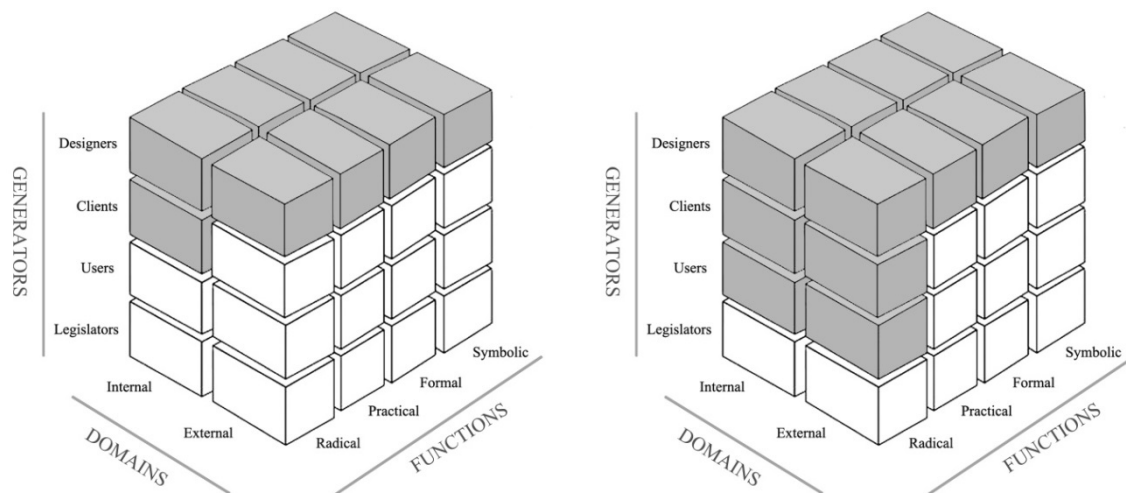


Figure 1 The constraints of design brief 1(left) and 2 (right)

As shown in the Figure 1, the model of design constraints is composed of three dimensions – the generators, domain, and functions of the design problem. The generators domain represents stakeholders who address design problems. It includes designers, clients, users, and legislators. In the case of brief 1, it holds design issues generated by the client, and each participant can discover additional problems as a designer. The second dimension is about the domain that the design problem concerns. In the case of product design, the internal domain could be defined as elements related to the product itself, and the external could be explained as the context or

environments that the product will be used. In this sense, the brief 1 only constrained the internal factors, while the brief 2 constrained both internal and external by defining the place where the chair will be utilized. The last domain is about the function or purpose of the constraints. The constraints of a design problem may suggest a required function of a product or a guideline for aesthetics. Depending on the functions of constraints, Lawson (2005) defined four different functions – radical, practical, formal, and symbolic. In the case of the design brief 1, participants were free to decide four different functions by themselves except the radical constraint defined by the client – a folding chair. However, the brief 2 defined additional constraints such as users and usage places.

2.3 Experimental setting and procedure

The experiment was conducted individually in a closed room equipped with a video recording device to record the participants' sketching activities, and the whole verbal data. A3 papers, pencils, pens were provided for the participants' use.

The design brief was provided as a written document which also explains the purpose and the procedure of this experiment. Half of the participants worked on the design brief 1 (fewer constraints), and the other half worked on the design brief 2 (greater constraints). While working on the design task, participants were asked to think out loud. Think aloud is a method to gather data about thinking through concurrent verbalization (Fonteyn, Kuipers, & Grobe, 1993; Someren, Barnard, & Sandberg, 1994). Several studies suggested that verbal protocols obtained through the think aloud provide valid and sufficient amount of information to understand the cognitive processes in a wide range of tasks (Ericsson & Simon, 1998; Russo,

Johnson, & Stephens, 1989). Although some researchers argued its influences on design activities (Davies, 1995; Lloyd, Lawson, & Scott, 1995), it has widely been utilized in the design researches which investigated the cognitive process of designers (Akin & Lin, 1995; Dorst & Cross, 2001; Fricke, 1996; Gero & Tang, 2001).

Before entering the main experiment, a short think aloud exercise was performed (Ericsson & Simon, 1998; Someren, et al., 1994). This exercise helped participants to become accustomed to the think aloud method. While working on the task for 1.5 hour, participants were not allowed to use external sources to obtain information or knowledge which they did not already have or could not retrieve, since this experiment aimed to investigate how people utilize memorized information, and its implication on the cognitive process.

DATA ANALYSIS

3 Analysis of the protocol

The verbal data from the think aloud method was firstly transcribed into text. 24 protocols were obtained through this process. While transcribing, the protocols were segmented based on verbal pauses and linguistic structure of verbal statements. These protocols were utilized as a main source of the analysis while they were supplemented by sketches of each participant. A huge of portion of silent moment was occurred when participants focused on visualizing their ideas. Hence sketches supported the design activities which were not verbalized. They also supported the identification of ideas which was a part of coding procedure. They also helped to clarify features or objects which were verbalized as pronouns.

3.1 Identifying a think flow

A cognitive act may correspond to several verbal segments rather than a single segment (Someren, et al., 1994). In order to understand the flow of cognitive process, verbal segments

were combined into a think flow which was defined as a consecutive thinking process with a single topic or a coherent perspective. Four different types of behaviours were employed as an indicator of the beginning of a new think flow. The first indicator was a comparatively long silence without any sketching or activities to progress his thoughts. In general, a silence more than 20 seconds was considered as a gap between two think flows.

The second indicator was an apparent switching of a topic or a perspective that a participant dealt with. Figure 2 shows a part of a protocol which demonstrates the moment that a transition between topics occurred. The participant thought about the problems of park benches, but suddenly moved his thoughts to reviewing the shape of existing subway chairs.

Are there any disadvantages of current park benches? Not really.... If I am forced to do so, may I can find some but.... Is it necessary? ... The current subway chairs look like a long bench, and...

Figure 2 A transition of topics which indicates a start of a new think flow

The third indicator was a behaviour that a participant moved back to the design brief, and start his/her thought process from the beginning. This behaviour was expressed verbally, and suggested a new attempt to understand the design problem differently. The last indicator is a closing comment of a thought which was verbally expressed by the participant. In general, there were two cases that participants expressed an ending of a thought. When a cognitive activity was concluded, participants often spoke out the ending and summarized the result. On the other hand, there were several cases that participants forced themselves to quit a think flow, and expressed it verbally. This case usually happened when a participant got stuck and was unable to move forward his/her thought. Figure 3 is an excerpt of a protocol which shows how a participant tried to stop a thinking compulsively.

So.. folded from the plane, and become a three dimensional one. Is there any other shape unlike the one designed by my colleague..? No, no. it is impossible right now. Too hard to generate a nes idea better than hers. It's difficult..

Figure 3 A forced ending of a think flow

In this research, a topic or a perspective was usually dealt with at the product level of which participants generated conceptual ideas. Hence the granularity of the topic is larger than other researches which focused on constructing features of a product (Dorst & Dijkhuis, 1995; Goldschmidt, 1991; Kavakli & Gero, 2002). Compared to linguistic segmentation which was done right after the transcribing, this identification process had more focus upon the contents of the protocols, which described the cognitive process of designers.

3.2 Coding procedure

While encoding, it is important to make the process as objective as possible. Based on the encoding procedure of a previous study (Gero & Mc Neill, 1998), this study focused on defining the each coding category precisely, and making the differences between two encoding non-significant through arbitration.

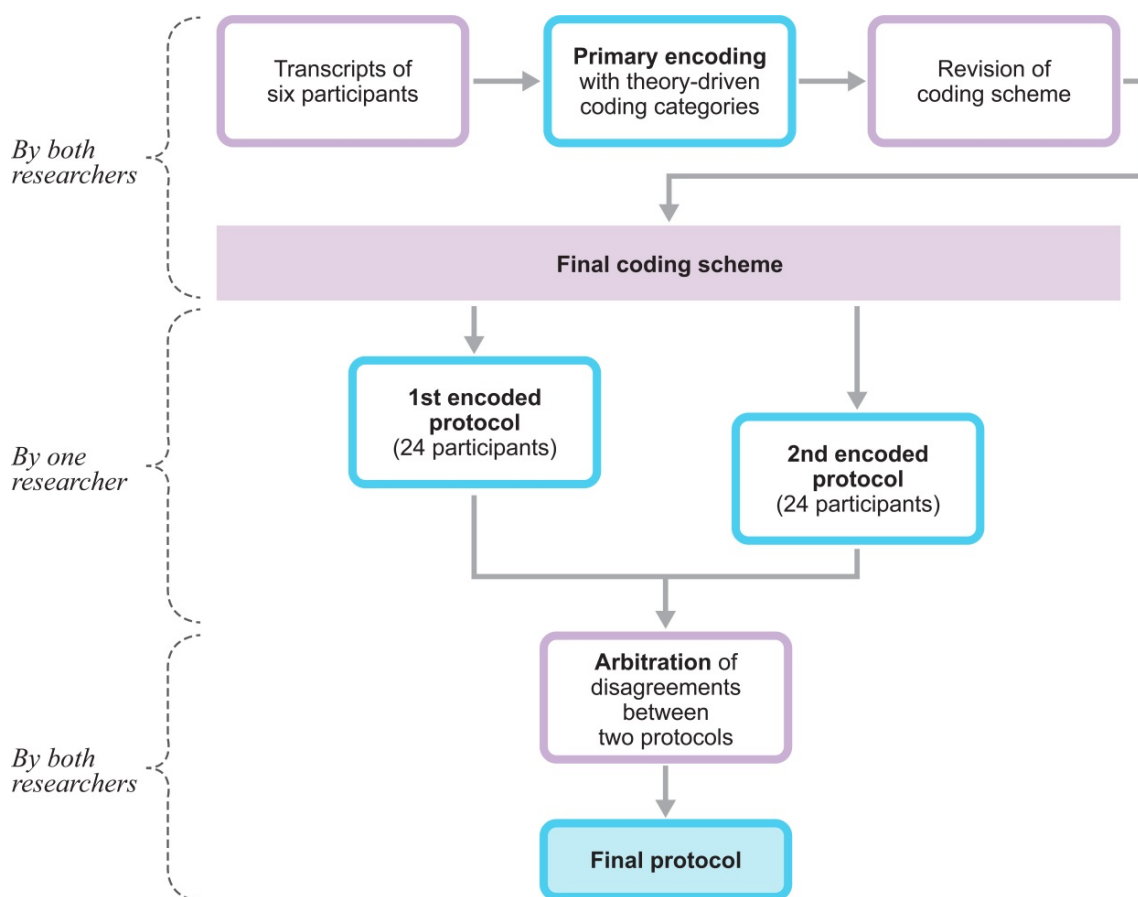


Figure 4 The coding procedure

The overall coding procedure is summarized in Figure 4. Primary encoding has done with transcripts of six participants. At first, a theory-driven coding scheme was utilized which was developed based on previous research (Jones, 1963; Tulving, 1991; Visser, 1995). During the

primary encoding process, a new category was evolved, the definition of each category was refined, and the final coding scheme was developed. Details of the final coding scheme are explained in the next section.

With the final coding scheme, the protocols of 24 participants were encoded twice. Only one of the researchers was involved in the encoding process. There was at least a month of time gap between the first encoding and the second encoding. This gap allowed the coder not to become fixated to the first encoding result. It also helped to look over the definition of each category and enhance the test-retest reliability. After finishing encoding, the first and the second encoded protocol were compared. The percentage of agreement for each coding category is listed in Table 1. Though two precedents categories showed more differences between two protocols, the level of agreement was reasonably high throughout all categories. These disagreements were arbitrated and adjusted based on the discussions of the two researchers, and the final protocol was obtained.

Table 1 The level of agreements between two protocols

<i>Coding category</i>	Ideas	Episodic precedents	Semantic precedents	Interpreters
<i>Percentage of agreement</i>	93.51%	89.04%	85.62%	94.36%

While comparing the two protocols and arbitrating disagreements, we found out that the level of agreement was underestimated due to the algorithm of NVivo10, a qualitative data analysis software utilized for encoding and coding comparison. NVivo10 uses character as its unit for coding comparison. It means that some part of disagreements recognized by NVivo10 is non-significant in terms of the overall meaning of encoded items. Hence it was expected that both the percentage of agreements and Kappa coefficients were higher than the presented values considering the salient points of encoded phrases or paragraphs.

3.3 The coding scheme

3.3.1 Ideas

An idea was defined as a design concept which was generated to satisfy the design brief, and has at least one determined feature related to the product itself such as shape, functionality, material, and etc. Depending on its novelty and the level of details, an idea was classified into one of three subcategories. A design concept which is novel in overall aspects was considered as an initial idea. If a concept is partially novel, in other words, if it was derived from other idea with partial alteration, it was regarded as a derived idea, which is a variation of original one. As an idea is developed with additional features and/or details, the developed one was classified into the category ‘developed ideas’. Table 2 explains the definition of each category.

Table 2 Definition of subclasses of Idea category

<i>Ideas</i>	<i>Initial ideas</i>	An initial design concept which is novel in overall aspects, and also satisfies the design brief.
	<i>Derived ideas</i>	A design concept which is partially modified from an initial idea.
	<i>Developed ideas</i>	A design concept which has more details or additional features compared to an initial idea.

3.3.2 Precedents - prior knowledge and experiences

In this research, the word ‘precedents’ represented the prior knowledge and experiences regardless of the domain that the knowledge was retrieved. The precedents were firstly classified depending on their memory types, and then assorted again regarding their role in the creative process.

In previous design researches, episodic and semantic memories were described as experiential and theoretical memory respectively (Lawson, 2004a, 2004b; Visser, 1995). They viewed episodic memory as a record of personal experiences, and semantic one as memories of intellectually acquired knowledge learned by study. This viewpoint concerns them as parallel subsystems of propositional memory (Nielson, 1958; Tulving, 1972, 1983).

More recent studies, however, support the interdependency between episodic and semantic memory (Dix, 2004; Tulving, 1991). New information from personal experiences could be stored in episodic memory, but its operation is supported by semantic memory. Unlike episodic memory, a semantic system could acquire new information without involving episodic memory as such theoretical knowledge could be learnt without personal experiences. But in some of its construction, information derived from episodic memory is utilized through perceptual systems.

The recent understanding of memory system was adopted in this study to develop the first level of the coding category – episodic and semantic precedents. Episodic precedents represent things retrieved from episodic memory systems, which have specific contexts and a direct relationship with personal experiences. When a participant retrieved a specific artifact, or a situation from personal event, it was regarded as an episodic precedent. Figure 5 is an excerpt of a protocol which contains an episodic precedent about a product that a participant saw in her grandmother’s house.

In my grandma's house, there is a chair.... without legs. No legs, only a sit pad and a backrest. My grandma uses this while watching a TV... Sitting on the floor..

Figure 5 An example of Episodic precedents from the protocol of participant O_F4

Semantic precedents are composed of two different types of semantic memory. Some semantic memories come from theoretical knowledge that participants have learnt or studied. The other part of semantic memories is created from the episodic knowledge through inference and generalization of it. In the case of later one, participants produce knowledge by themselves through combining several personal experiences and/or reflecting theoretical knowledge upon their personal experiences. Figure 6 shows an example of this type of semantic precedents which is related to a prototype of chairs.

Usually, chairs have legs.. legs.... and a chair means... A chair can be defined something with a backrest, a seat pad, and legs..

Figure 6 An example of Semantic precedents from the protocol of participant

The second level of the coding categories considered the role of each precedent in the creative process. A generalized model of the design process was adopted, which described it as an iteration of analysis, synthesis, and evaluation (Jones, 1963; Lawson, 2005; Wynn & Clarkson, 2005). Episodic and semantic precedents were encoded again depending on their contribution on the design process. During the encoding, however, the analysis category was revised because two distinctively different usages of precedent utilization were revealed. A part of precedents involved in analyzing the design problem, while the other part contributed to analyze the promising range of solution. In order to define these two different usages, the concept of problem and solution spaces was employed (Dorst & Cross, 2001; Maher & Poon, 1996).

Let's think about the existing folding chairs. ... A wheelchair...
In a church or a huge auditorium, folding chairs are usually utilized. Unfold and install them, after an event, fold them and store. Yes, in order to save the space. Yes, space saving...

Figure 7 A precedent which was used to analyze the problem space

The precedent shown in the Figure 7 is utilized to analyze the problem. The participant reviewed an existing product to discover a laden meaning of the design problem. The analysis of the problem space included redefining the problem and examining existing or similar solutions.

If the flat is fully equipped... tables, chairs, everything might be there already. And living alone, no needs to be flexible. If there is a chair already, yes, you don't need an additional folding chair. So, I'd better think about a flat without an existing chair, maybe a... kind of a lifestyle sitting on the floor..?

Figure 8 A precedent which was used to analyze the solution space

The precedent in the Figure 8 shows an investigation of the solution space. The participant made a conjecture based on her prior experiences to understand the context that a folding chair would be needed. The analysis of the solution space includes understanding the users, the place, and the context which become a background for developing solutions. The finalized coding scheme of precedents is listed in the Table 3.

Table 3 Final coding categories of precedents

<i>Type of memory</i>	<i>Role in the design process</i>
<i>Episodic precedents</i>	Analysis of the problem space
	Analysis of the solution space
	Synthesis
	Evaluation
<i>Semantic precedents</i>	Analysis of the problem space
	Analysis of the solution space
	Synthesis
	Evaluation

3.3.3 *Interpreters*

During the primary analysis of protocols, another type of cognitive factor was identified which is largely participated in the idea generation process. The factor was a conceptual theme which was too generalized to be categorized as a precedent. It was named as *Interpreters*, because it helped to interpret the meaning of the design brief, and engaged in manipulating the problem space. There have been several studies which support the participation and contribution of interpreters in the design process. Lawson (2005) argued that a design problem can be subjectively perceived and interpreted due to its innate nature. An experimental result of designing a restaurant for birdlike creatures showed that how much the design direction and outcomes could be changed depending on the interpretation of the design task (Sifonis, 1995). Dorst and Cross (2001) also reported an interpreting behaviour of designers which includes redefining the design problem based on the understanding of their own resources and capabilities (Dorst & Cross, 2001).

Well.. Ah..! I was really biased. A folding which folds the chair...No. If I fold papers, and utilize them as a module... Then build a chair. This kind of chair... could be a folding chair. Yea maybe..? So, not folding the chair itself, but a chair made with folded modules. Fold, fold, fold, and combine them.

Figure 9 An example of *Interpreters* from the protocol of participant X-F6

Based on the previous studies and the evidence from the protocols of this research, *Interpreters* were determined as a category of the final coding scheme. Figure 9 shows an example of interpreters from a protocol. The participants X-F6 suddenly perceived a new meaning of a folding chair which was different with the understanding that she had employed.

3.3.4 Relationships among encoded items

Throughout the whole design process, several think flows were made, and various elements were utilized. There was a sequential order among think flows, and also among the encoded elements in a think flow. Especially in a think flow, each item had directional linkage which represented the order of retrieval or utilization. These sequential relationships supported the analysis the encoding results from the viewpoint of a process.

The other relationship was related to each item's contribution on idea generation. Among precedents and interpreters which were mentioned during the entire design exercise, some items were involved in the idea generation process, but some were not. Any precedent or any interpreter which was participated in idea creation had a relationship with the idea that it contributed to. While encoding, this relationship was also identified and encoded as an attribute of each item.

4 Visualization of the cognitive process

Although the encoding of protocols was now completed, it does not mean that the protocols are ready to explain their meaning and findings by themselves. The encoded protocols require analysis and interpretation. In order to describe their findings, previous protocol studies had devised a variety of methods.

One of the most common and straightforward way is presenting an excerpt of a protocol which represents certain aspect clearly (Dorst & Cross, 2001; Schon & Wiggins, 1992). A part of the protocol is extracted from the entire protocol in verbatim, and researchers furnished explanatory notes or interpretations to describe their encoding methods and/or findings. It helps readers to understand what researchers did and found by looking at the raw data. But it becomes cumbersome when too many texts are provided without processing. Using only extracted text may make the paper dispersed and unstructured.

A frequency chart has often been used to display the quantitative data of encoding categories. Especially in studies to investigate the design process, a frequency chart was often combined with a timeline which shows the distribution of coded items along the process (Akin & Lin, 1995; Eckersley, 1988; Suwa, et al., 1998). It displays a sequential flow to trace the cognitive activities based on occurrence of different coding categories. This kind of time-ordered displays support understanding of process and its cognitive factors.

Though such displays have provided valuable insights, still there have been limitations in their ability to express the richness of protocol data. For instance, the protocol which was fragmented into coding categories rarely explained the inter-relationship between encoded items. Reminding the complexity of design process and its cognitive activities, the creation and use of various methods should be encouraged in order to expand our understanding about design.

In this regard, this study created a new way of displaying the encoded protocol with the aim of better representing the cognitive process of designers. This new graphical representation named,

‘cognitive mapping’ focuses on visualizing expansion and progress of thinking, and relationships between cognitive factors which were involved in the design process.

4.1 Constructing a cognitive map

In construction of a cognitive map, discrete think flows, encoded items of four coding categories, and relationships among encoded items were utilized. Every encoded item from four different types of encoding categories – ideas, episodic precedents, semantic precedents and interpreters – were represented as a single figure depending on their categories. The sequential relationships were visualized as arrows, and an idea and items involved in the idea generation were clustered into a package. Figure 10 shows a partial cognitive map of participant *X-F3* with a legend.

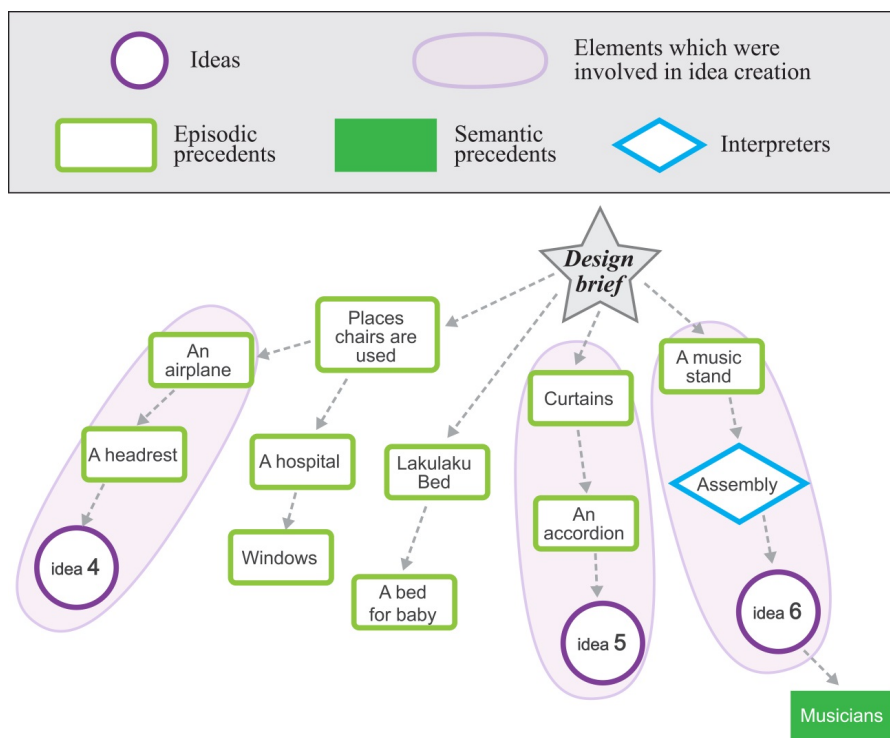


Figure 10 A part of cognitive map with a legend

The design brief which was visualized as a grey star was the starting point of each think flow. The first element of a think flow connected with the design brief, and the following elements were linked to each other in successive order. Although most of the think flows started at the design brief, certain think flows linked to other flows consecutively because the beginning of new flows were derived from the elements of other think flows.

4.2 Analysis of cognitive maps

While reviewing the cognitive maps of 24 participants, we realized that the maps could be classified into several categories even though the maps were quite varied in their shape. The diversity of shapes implied that the cognitive process of each participant was also various as well. Even so, different types of similarity among cognitive maps suggested the possibility to categorizing cognitive maps. As a preliminary analysis, we analyzed 24 cognitive maps based on their shape, and classified them into three different types. The first type was a cognitive map which looks divergent, the second one was a convergent one with a few series of think flows, and the final one was a combined shape of divergent and convergent flows. Figure 11 shows three cognitive maps which represent each type.

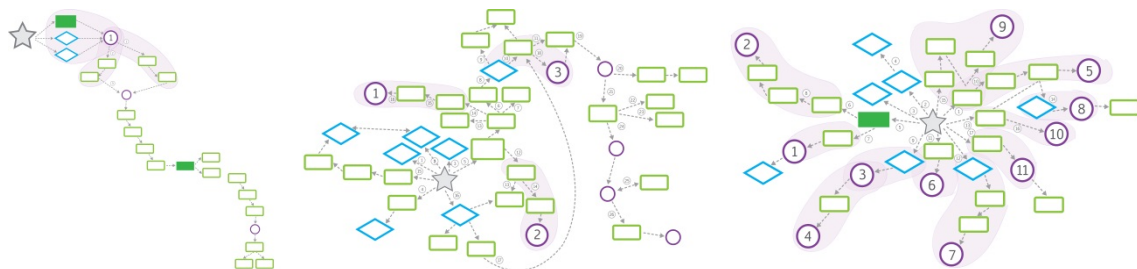


Figure 11 Three different types of cognitive maps classified by researchers

In order to increase the objectivity of classification, researchers utilized a social network analysis tool NetMiner for verification. NetMiner is a software which analyzes a social network constructed by node data and link data. Node data is composed of independent entities which have their own attributes. Thus the concept of node corresponds to the encoded item of a protocol in this study. Each encoded item was defined as a node, and the coding category was assigned as an attribute value. Link data which defines the linkage among nodes corresponds to the relationship among encoded items in this study. Items in a think flow have directional linkages depending on their order of utilization. This kind of relationship was defined as a target-source relationship (Huisman & Van Duijn, 2005; J. Scott, 1988). In the case of a relationship between an idea and an item contributed to the idea was defined as a non-directional link data (Huisman & Van Duijn, 2005).

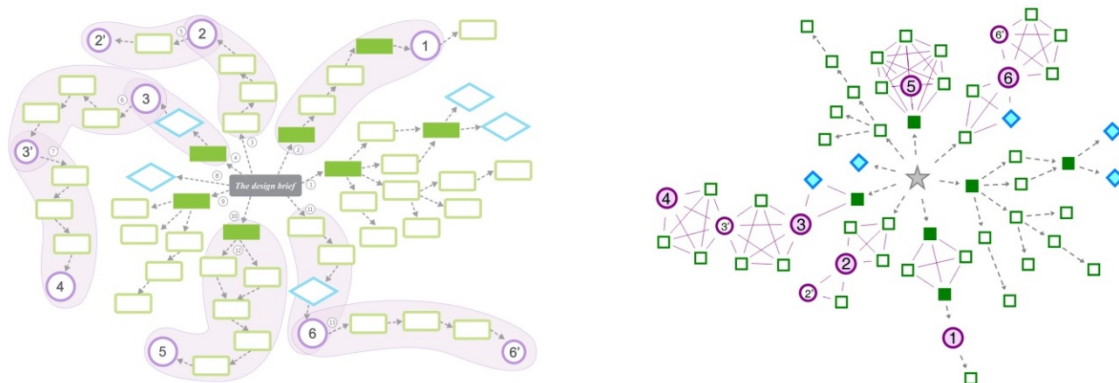


Figure 12 Comparison of graphical representations generated by researchers(left) and NetMiner (right)

The encoding results of 24 protocols were converted into NetMiner network data. Figure 12 provides a comparison between a hand drawn cognitive map and a cognitive map visualized by NetMiner. Both maps were generated based on the encoded protocol of participant *O-F2*. The similarity between two graphics suggested that the formation of hand drawn cognitive map was quite reasonable, and the encoded results were well preserved while it was converted to network data.

RESULTS

5 Quantitative analysis of encoding protocols

The encoded data was statistically analyzed. Table 4 summarizes the types of quantitative data which were utilized for analysis. The numbers of think flows and ideas are factors related to the creative activities of participants. The numbers of precedents and interpreters have a relationship with the utilization of prior knowledge and experiences. The effect of constraints was examined by one-way ANOVA. The results investigated the influence of different level of constraints upon think flows, generated ideas, and precedents utilization. After that the precedents were reviewed in terms of their role in the creative process.

Table 4 Categories of quantitative data obtained through segmentation and encoding

	Think flows which have no relationship with idea generation	
<i>Number of think flows</i>	Think flows which are related to idea generation	Related to an initial idea
		Related to a derived idea
		Related to a developed idea
<i>Number of ideas</i>	Number of initial ideas	
	Number of derived ideas	
	Number of developed ideas	
<i>Number of precedents</i>	Number of episodic precedents	Utilized for analysis of the problem space
		Utilized for analysis of the solution space
		Utilized for synthesis
	Number of semantic precedents	Utilized for evaluation
		Utilized for problem space analysis
		Utilized for solution space analysis
		Utilized for synthesis
		Utilized for evaluation
<i>Number of interpreters</i>		

5.1 Effect of constraints on the creative process

At first, the effect of constraints was examined in terms of its influence on the creative outcomes. Table 5 shows the average number of total think flows, initial ideas, and developed ideas depending on the design brief that participants received. These three values had relatively strong impact on designers' cognitive process, and represent the outcomes of the creative process. If designer had more think flows, his/her design process was much more fragmented and composed of various topics as suggested the segmentation of the protocols. In the case of

designers who generated comparatively more initial ideas, he/she had spent more time to generate conceptual ideas than others who specified the details of each idea as a developed idea.

Table 5 The average number of think flows and ideas depending on the level of constraints

	Number of think flows		Number of initial ideas		Number of developed ideas	
	Mean	SD	Mean	SD	Mean	SD
<i>Design brief 1 : less constrained</i>	19.75	8.98	7.42	5.60	2.42	2.54
<i>Design brief 2 : more constrained</i>	20.42	6.67	6.25	4.63	2.58	2.61

The result of an independent sample t-test indicated that there was non-significant difference for the less constrained design brief over the more constrained one. I used a significance level of .05 for all statistical tests. This indicates the level of constraints of the design problem has little influence upon the creative outcomes of designers. However, there was a statistically significant difference in utilizing precedents in terms of their memory type and roles in the creative process. Table 6 shows the average percentage of episodic and semantic precedents depending on the level of constraints. The result of t-test revealed that the proportion of episodic precedents is significantly higher in the more constrained problem, $t(22) = 2.187, p = .04$. This implies that designers may utilize fewer episodic precedents and more semantic ones when they worked on the design brief with more constraints.

Table 6 The average proportion of utilized precedents depending on the level of constraints

	Episodic precedents		Semantic precedents	
	Mean	SD	Mean	SD
<i>Design brief 1 : less constrained</i>	94.44	5.39	5.56	5.39
<i>Design brief 2 : more constrained</i>	88.49	7.74	11.51	7.74

Table 7 shows the average proportion of precedents utilized for analysis, synthesis, and evaluation. The level of constraints also had a significant influence on the proportion of precedents utilized for analysis of the problem space ($t(22) = -3.120, p = .007$) and synthesis of the solutions ($t(22) = 2.465, p = .022$). The analysis shows that the proportion of precedents for analysis of the problem space was significantly lower in the less constrained brief. However the proportion of precedents for synthesis was significantly higher when designers were dealing with fewer constraints.

Table 7 The average proportion of precedents utilized for analysis, synthesis, and evaluation

The role of precedents	Analysis of the problem space*		Analysis of the solution space		Synthesis*		Evaluation	
	Mean	SD	Mean	SD	Mean	SD	Mean	SD
Design brief 1 : less constrained	7.03	6.17	26.93	17.39	62.13	18.42	2.29	3.58
Design brief 2 : more constrained	22.37	15.88	27.66	10.23	45.48	14.42	4.62	5.05

*. The mean difference is significant at the .05 level.

In summary, the level of constraints had non-significant influence on the number of ideas and think flows, but significantly affected to the utilization of precedents. Figure 13 and Figure 14 illustrate the significant differences between the less constrained brief and the more constrained one.



Figure 13 The average proportion of episodic and semantic precedents depending on the level of constraints

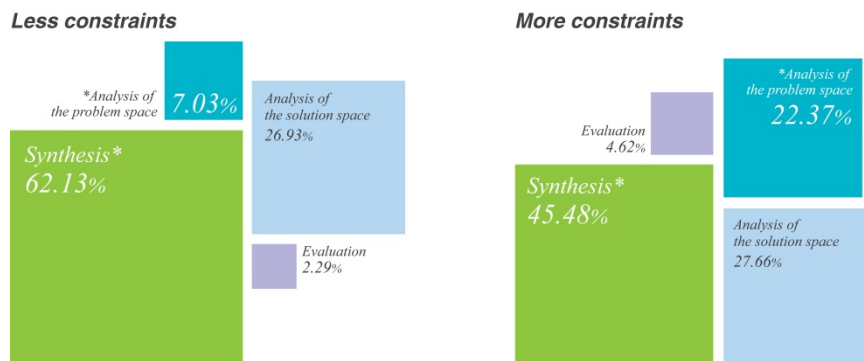


Figure 14 The average proportion of precedents depending on their roles in the creative process

The results imply that the creative activities of designers may be less susceptible to the constraints that designers encountered while designing an ordinary product. It seems that the ability to generate a variety of novel ideas is an intrinsic capability of designers. However, this study suggests designers may change the types of precedents and their utilization depending on the design brief while they generated same number of ideas regardless of the design brief.

These results indicate the importance of understanding the capability of designers, and this will be discussed further in the following section. It also suggested the way to assist designers to deal with constraints better. In the case of product design, designers may employ more semantic

knowledge when they are engaged in more constrained problems. Hence providing relevant semantic knowledge could facilitate the creative process of designers when they are managing constraints. The increased amount of constraints requires more analysis of the problem space. However, the constraints reduce the utilization of precedents in the synthesis process. Due to the increased amount of constraints, it seems that designers may become more conscious of the problem itself rather than generating the solutions while they investigating relevant information from their memory system. In this regard, providing useful information and knowledge for the problem space may support and facilitate the creative process of designers.

5.2 Episodic knowledge - dominant and essential

Based on the frequencies of encoded items, the proportion of episodic precedents and semantic precedents were compared. As previously explained, one encoded precedent meant a bundle of information which was related to a single topic. Hence the proportion represents not the quantity of information but the number of topics which embrace a segment of related information. Table 8 displays the average percentage of each precedent throughout the whole protocols of 24 participants.

Table 8 The average proportion of episodic precedents and semantic precedents

	Episodic precedents	Semantic precedents	Total
<i>Average proportion</i>	91.47%	8.53%	100%
<i>Standard deviation</i>	7.20	7.20	-

The result suggests a dominant usage of episodic precedents. The relatively low value of standard deviation implies that this dominance is general to most of the participants. Although the importance of episodic knowledge in design process has been emphasized by several studies (Lawson, 2004b; R. Oxman, 1990; Visser, 1995), there have been few attempts to demonstrate its significance based on comparable data. It seems that approximately 90% of all information is retrieved as a type of episodic knowledge. It clearly shows that episodic knowledge is dominantly involved in the retrieval and utilization of prior knowledge throughout the overall design process.

Another indication of importance of episodic knowledge is that every semantic precedent was utilized with at least one episodic precedent. In other words, none of the semantic precedents were utilized for idea generation without episodic experiences. This result supports not only the

dominance of episodic precedents, but also its vital role in the creative process. Designers may not be able to make use of semantic knowledge if they don't have episodic experiences related to it. This phenomena may also relate to the theory of the organization of prior knowledge suggested by Oxman (1990), and proposes a further explanation of the relationship between episodic and semantic precedents. According to Oxman's theory, episodic experiences act as indices for memory structurization and its retrieval (R. Oxman, 1990). In the most cases, the episodic and semantic memories were accompanied with each other, and this assists the theory. In the protocols of this study, however, several cases were observed that a semantic precedent induces a series of episodic precedents. In this case, a semantic precedent behaved as an index to search and reactivate related episodic knowledge. Thus it could be concluded that episodic knowledge is essential to utilization of prior knowledge, but both of episodic and semantic knowledge contribute to searching and retrieval of memories.

6 Cognitive styles in the creative process

A cognitive map enables us to look over the comprehensive structure and configuration of a cognitive process. This contrasts with the quantitative analysis of encoding results which have been utilized commonly. Based on the interpretation of cognitive maps, three phases of the cognitive process were identified – exploration, generation, and development. For each phase, the encoding results were examined much more thoroughly to investigate the cognitive characteristic of designers. Finally, the cognitive characteristics of each phase were aggregated, and interpreted as a comprehensive cognitive style of a designer.

6.1 Phases of the creative process

The cognitive maps of participants showed that there were three different types of think flows. The first one is a think flow which solely composed of precedents or interpreters. It means that this think flow does not contribute to formulating an idea. A second one is a think flow which has a relationship with an initial idea. It suggests that precedents in the think flow were utilized for generating an initial concept. The last one is a think flow related to a developed idea, which shows the process of refining an idea. Figure ## highlights the three different types of think flows in a cognitive map.

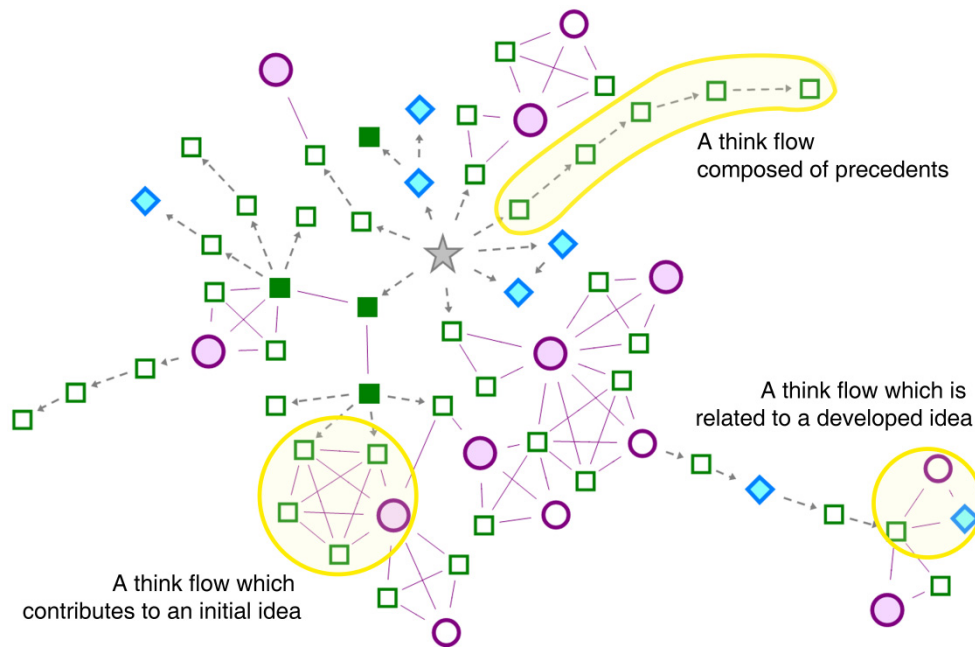


Figure 15 The average proportion of episodic and semantic precedents depending on the level of constraints

These three types of think flows suggest the existence of three procedural phases of design process – exploration, generation, and development. Each phase consists of different mental activities in terms of its utilization of prior knowledge and experiences.

The first phase that every participant showed is the exploration phase which includes the retrieval of prior knowledge from memory, and searching for associations between the design problem and retrieved knowledge. All participants had at least a think flow which is composed of precedents, but does not contribute to idea formation. This indicates that exploration is a distinctive part of cognitive process that designers continuously explore precedents to find possible associations with the problem.

The second phase is a generation phase, where novel and/or discrete design concepts are formulated. Among precedents which were explored during the first phase, only some of them were utilized in this phase. Think flows related to an initial idea or a derived idea show the

generation process that a participant experienced. Although all participants had this phase, the cognitive style and its outcome were quite varying.

The last phase is a development phase that an initial design concept is improved in terms of its details. Think flows of this phase begin with an idea which is generated in advance. Designers started with an initial design concept, and tried to elaborate it while utilizing their prior knowledge and experiences. Unlike previous two phases – exploration and generation – the development phase was observed from a group of participants.

The significant insight of this division is the distinction between the retrieval of prior knowledge and the generation of new ideas. Although various models of the creative process have been suggested, they regarded the process of exploring relevant knowledge as a part of the generation phase, or a preparatory step of it. In the case of the Genevieve model suggested by Ward, Smith & Finke (1999), the retrieval of prior knowledge is described as one of the elements which constructed the generation phase. The four-stage model is a classical description of the creative process which has been reviewed and revised by many researchers (Busse & Mansfield, 1980; Cagle, 1985; Lubart, 2001; Patrick, 1937; Wallas, 1926). The first stage is the preparation which includes an analysis and defining of a problem. In the preparation stage, the exploration and retrieval of relevant knowledge is described as an activity which could be done. The model devised by Bassadur and his colleagues (2000) gave more emphasis on the exploration of knowledge by regarding it as one of eight steps. Although several researches have suggested the distinction between idea generation and retrieval of relevant knowledge, there has been few attempts to investigate the different cognitive aspects of the two phases (Amabile, 1996; Getzels & Csikszentmihalyi, 1976). The protocols of this study proposed a clear distinction between the exploration and the generation as well as the change of cognitive styles across the two phases. In this regard, the identification of three phases – exploration, generation, and the development - provides an means to examine the creative process and their cognitive styles.

6.2 Cognitive styles in each phase

6.2.1 In the exploration phase

Every precedent which was mentioned in the protocol had been explored as a part of the design process regardless of its contribution to idea generation. Some designers retrieved a variety of topics and precedents related to the design situation. Some designers rather focused on a limited number of topics. In order to identify the cognitive characteristic of the exploration phase, the number of think flows and the closeness centrality of each cognitive map were calculated and employed for a cluster analysis.

The number of think flows represents the diversity of precedents retrieved from the memory system. It increases as more diverse topics are retrieved and explored. The diversity also affects the shape of a cognitive map. As more topics were mentioned, the cognitive map appears more dispersed.

The closeness centrality measures not only the diversity but also the extent of the uniformity of topics. If a designer progresses his thought further within a single topic, the length of the think flow is relatively longer than other think flows. In contrast, the cognitive map of a designer who explores diverse topics in a similar level of progress looks well-distributed.

The closeness centrality of a cognitive map was analyzed in NetMiner. In more detail, a closeness centrality index was utilized which is a measure of closeness centrality of a network (Freeman, 1978). It enables the comparison between networks which have different number of nodes and links. The index calculates a centrality score based on geodesic distances among nodes, and the score ranges from 0 to 1. If a network is extremely centralized like as a star graph (Figure 16), the closeness centrality index is 1.

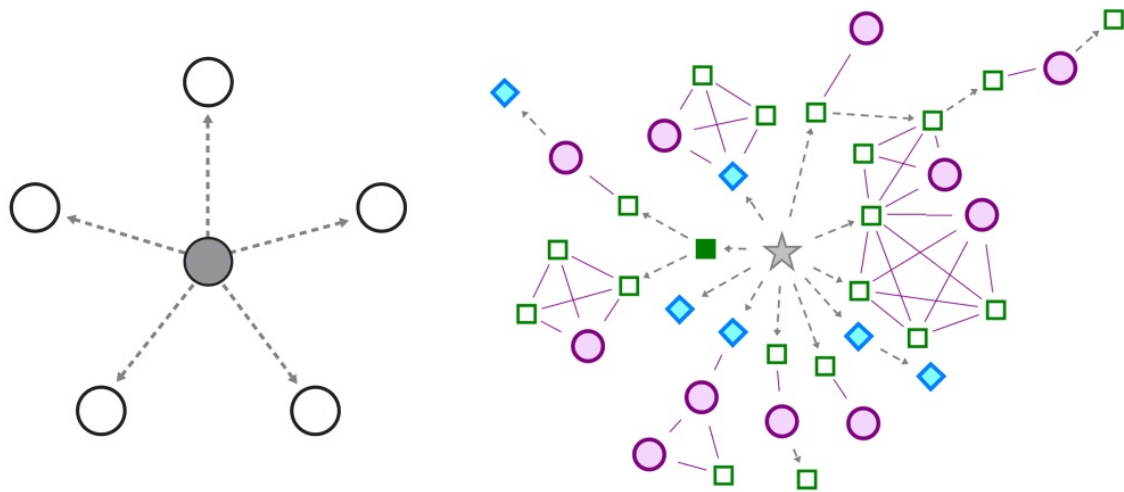


Figure 16 An example of highly centralized graph with a star shape, and a cognitive map of the highest value of centralization index.

Figure 16 shows the most centralized cognitive map of participant *X-M3*. In this study, the closeness centrality score near to 1 indicated a cognitive process composed of several think flows with a similar level of progress. As the centrality score closes to 0, the cognitive map becomes less distributed and concentrated on fewer topics. Table ## shows the centrality index score of 24 networks. The highest index score which represents the most centralized network is .53, and the lowest score is .02.

Table 9 Closeness centrality index score of networks of each participants

		<i>Design brief 1 : design a folding chair</i>											
		<i>M1</i>	<i>M2</i>	<i>M3</i>	<i>M4</i>	<i>M5</i>	<i>M6</i>	<i>F1</i>	<i>F2</i>	<i>F3</i>	<i>F4</i>	<i>F5</i>	<i>F6</i>
<i>Closeness Centrality Index Scores</i>		.19	.02	.52	.36	.14	.22	.44	.36	.42	.05	.27	.34
		<i>Design brief 2 : design a folding chair for 20-30s who live in a flat</i>											
		<i>M1</i>	<i>M2</i>	<i>M3</i>	<i>M4</i>	<i>M5</i>	<i>F1</i>	<i>F2</i>	<i>F3</i>	<i>F4</i>	<i>F5</i>	<i>F6</i>	<i>F7</i>
<i>Closeness Centrality Index Scores</i>		.49	.28	.14	.28	.05	.11	.35	.33	.26	.33	.45	.42

A hierarchical cluster analysis was run on the number of total think flows and the score of closeness centrality index using centroid linkage method. Based on the preliminary classification done by the researchers, the number of clusters was determined as three.

As shown in the Table 10, six participants belong to the cluster 1, thirteen participants to the cluster 2, and the remained five participants are clustered to the third one. In the clustering result, there was no significant difference influenced by the level of constraints provided as a design brief.

Table 10 A numerical description of each cluster in the exploration phase

	<i>Number of participants</i>	<i>Average number of think flows</i>	<i>Average closeness centrality index scores</i>
<i>Cluster 1: limited exploration</i>	6	13.17	0.09
<i>Cluster 2: moderate exploration</i>	13	19.54	0.32
<i>Cluster 3: divergent exploration</i>	5	32.40	0.43

The six participants of cluster 1 showed limited exploration composed of comparatively fewer numbers of think flows – on average around thirteen think flows. The average closeness centrality score is 0.09. The value near to zero indicates the cognitive map maybe imbalanced and less divergent. These values confirm that the participants in cluster 1 explored their prior experiences within limited topics, and advanced their thinking in certain topics discriminately as indicated in the mapping.

The participants of cluster 3 present a sharp contrast to the one belonging to cluster 1. They appeared to retrieve a wide range of topics in the exploration phase, and dealt with each topic somewhat more evenly. The divergent characteristics of cluster 3 participants was supported by the average number of think flows – approximately 32 which exceeds by double that of cluster

1's – and the average closeness centrality score. The half of the participants who belong to cluster 2 showed a moderate exploration. That is, they stayed in the middle of the limited and the divergent exploration in terms of the number of think flows and the centrality of their cognitive maps.

6.2.2 In the generation phase

While generating solutions, each participant showed different cognitive patterns. Some participants preferred to generate various concepts. Contrary to this, others rather preferred to generate an idea and improve its details.

I investigated the cognitive styles in the generation phase using the number of initial ideas, and the number of think flows related to initial ideas generation. Although derived ideas and developed ideas were also the outcomes of the generation process, I focused on the initial ideas which were more fully novel and original. Initial ideas are generated at the first moment where designers were able to associate their prior knowledge with the given design problem. Derived and developed ideas depend on initial ideas. Thus I can conclude that the generation of initial ideas demonstrates the existence of a pure creative activity.

Using a hierarchical cluster analysis, three clusters were determined based on the number of initial ideas think flows related to them. Table ## shows the results of the clustering. In the same way as the exploration phase, there was no significant effect of constraints on the cognitive styles in the generation phase.

Table 11 A numerical description of each cluster in the generation phase

	<i>Number of participants</i>	<i>Average number of initial ideas</i>	<i>Average number of think flows (initial ideas)</i>
<i>Cluster 1: limited generation</i>	10	1.70	1.70
<i>Cluster 2: moderate generation</i>	12	9.58	11.00
<i>Cluster 3: divergent generation</i>	2	16.00	17.50

As described in the Table 11, ten out of all participants generated limited numbers of initial ideas. The participants classified as the cluster 1 utilized 1.7 think flows to generate 1.7 initial ideas in average. Both in number of think flows and the ideas, these participants were extremely limited in the creation of novel concepts. Contrary to the cluster 1, two participants in the cluster 3 showed a strong divergence in the creation of initial ideas. Many think flows and initial ideas indicate that the two participants generated various ideas which are discrete to each other. Half of the participants belong to the cluster 2, which is a medium between the cluster 1 and 3 in terms of the diversity of created ideas.

6.2.3 In the development phase

Among 24 participants, only fifteen designers showed a development phase which includes refining their initial ideas with more details. Except the nine participants who did not generate any developed ideas, fifteen participants were classified into two categories depending on the number of developed ideas and the think flows related to them. The ratio between the number of initial ideas and developed ideas was considered to determine the level of development. Table

12 shows the number of participants for each cluster, the average number of developed ideas, and the average ratio of the developed ideas to the initial ideas.

Table 12 A numerical description of each cluster in the development phase

	<i>Number of participants</i>	<i>Average number of developed ideas</i>	<i>Average ratio of the developed ideas to initial ideas</i>
<i>Cluster 1: no development</i>	9	0	0
<i>Cluster 2: primary development</i>	7	3.43	0.45
<i>Cluster 3: progressive development</i>	8	4.75	4.22

The difference between the cluster 2 and the cluster 3 is less evident in the average number of developed ideas. However the ratio of the developed ideas to initial ideas suggests a significant difference between the two groups. The participants in the cluster 3 developed a single idea further, and the level of development is more progressive than the participants of cluster 2.

In cases of the exploration and generation phases, every participant showed cognitive activities related to the two phases regardless of differences in the degree of divergence. In the case of development phase, however, nine participants didn't make any attempt to develop an idea. This result implies that convergent thinking to improve an idea is not an essential part of the creative process depending on the cognitive style of designers.

6.3 Four cognitive styles in the creative process

A comprehensive cognitive style of each participant was identified by integrating the cognitive styles of three phases. A total of four cognitive styles were distinguished according to the transition of cognitive styles between phases, and the significant characteristics of each phase. The name of each cognitive style was decided by reflecting the key features of each style – *Focused Probers*, *Treasure Hunters*, *Selectors*, and *Explorers*. Figure 17 illustrates identification of the holistic cognitive styles through integrating cognitive styles of each phase.

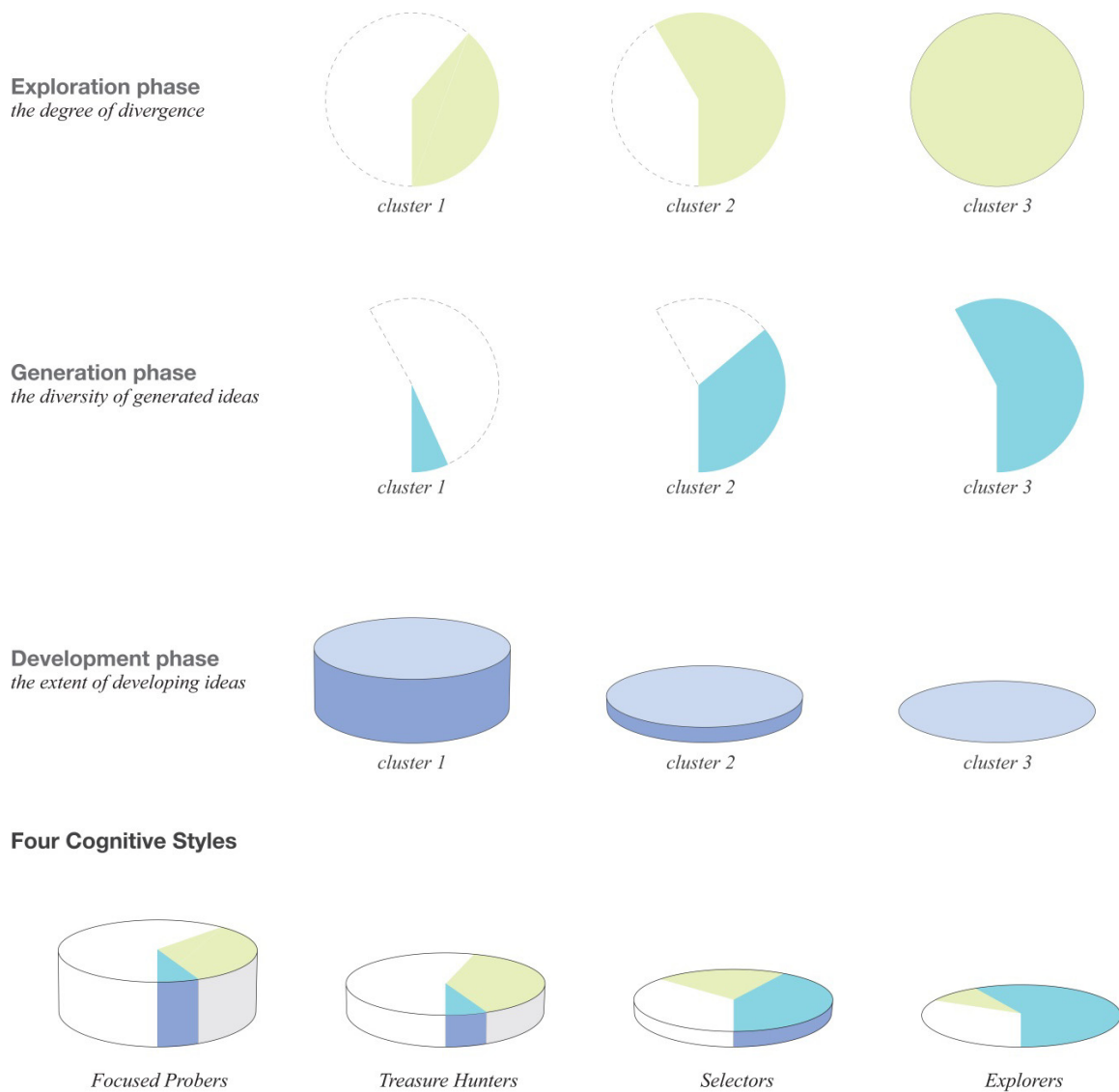


Figure 17. The cognitive styles of each phase and the four different holistic cognitive styles

In this section, the cognitive process of each style will be discussed in terms of their exploration and generation of ideas. The differences in the utilization of precedents will be described in the following section.

This is not the first attempt to classify the cognitive styles of the creative process. Although a limited number of studies have done in the design discipline, there have been various studies focused upon cognitive styles in the creativity research field and psychology (Brophy, 2001; Cross, 1985; Khandwalla, 1993; Kvan & Jia, 2005; Martinsen, 1995; Riding & Cheema, 1991). However this study is unique and significant in terms of its method in the classification of cognitive styles. That is, this study identifies the holistic cognitive styles by integrating the styles of three phases of the creative process. It provided a more elaborated explanation than the results of previous studies which defined the cognitive style without considering different steps of the creative process (Cross, 1985; Kvan & Jia, 2005; Tovey, 1984).

In addition, this study examined the cognitive process itself in order to identify the cognitive styles. I analyzed and utilized the cognitive activities of designers as an indicator of the cognitive style. In contrast, previous studies rather utilized a pre-developed scale or an inventory to assess cognitive styles of participants (Basadur, Graen, & Wakabayashi, 1990; Brophy, 2006; Kirton, 1987; Kvan & Jia, 2005; Martinsen, 1993). Most of the scales were composed of questionnaires which were far removed from the general design problems. Thus previous studies had limitations to describe the cognitive styles of designers who usually dealt with complex and multifaceted problems.

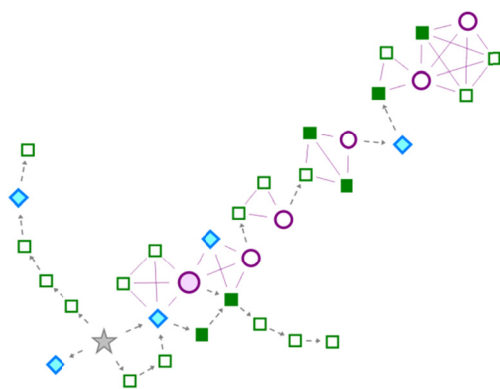
Table 13 describes the characteristics of each cognitive style through the number of participants and the average number of initial ideas. Figure 18 show the four cognitive maps which represent each cognitive style.

Table 13 The cognitive characteristics of four cognitive styles and the average of initial ideas

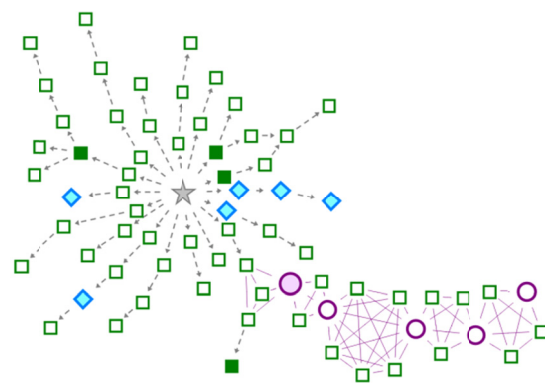
	<i>Focused Probers</i>	<i>Treasure Hunters</i>	<i>Selectors</i>	<i>Explorers</i>
<i>Number of participants</i>	6	4	5	9
<i>Average of initial ideas</i>	1.17	2.25	9.20	11.33
<i>The degree of divergence in the exploration phase</i>	+	++, +++	++, +++	++, +++
<i>The diversity of generated ideas</i>	+	+	++, +++	++, +++
<i>The extent of developing ideas</i>	++	+, ++	+	none

The ‘*Focused Probers*’ include six participants who showed a limited and focused cognitive activity throughout the whole process. They retrieved limited numbers of topics in the exploration phase, and generated fewer ideas – on average 1.17. Instead of creating more design concepts, they developed each idea deeply with great amounts of detail.

The second cognitive style is named as ‘*Treasure Hunters*’ which is characterized by the relatively fewer number of initial ideas compared to the explored precedents. Four participants belong to this group. Although the divergence level of exploration was moderate or high, the participants generated only 2.25 ideas on average. They all showed the cognitive phase of developing initial ideas, though the level of development differs within the group of participants.



Focused Probers



Treasure Hunters

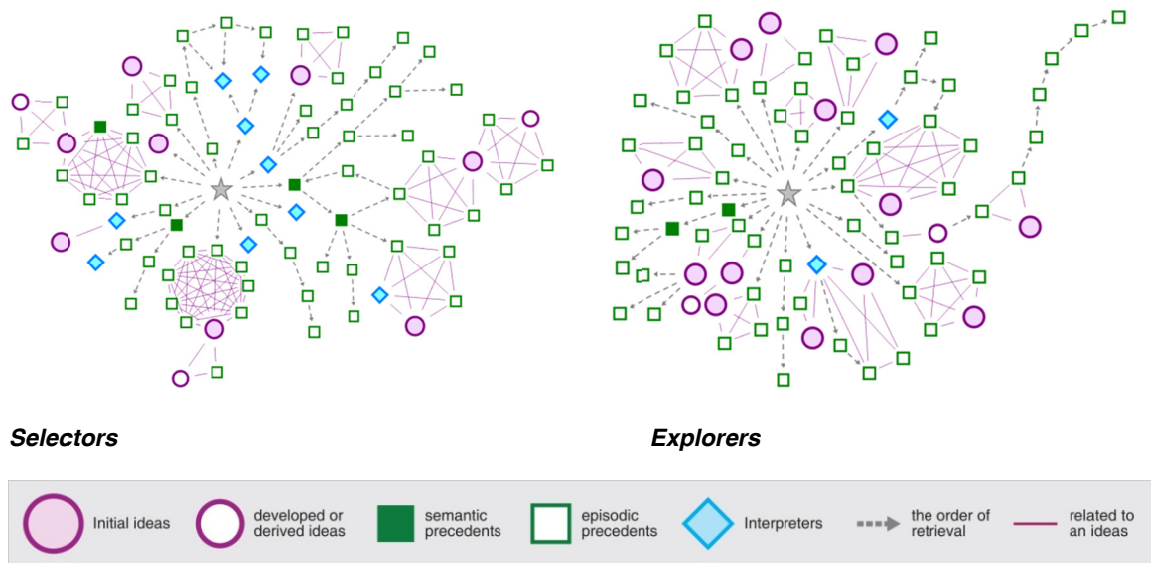


Figure 18 Cognitive maps of four cognitive styles

The ‘*Selectors*’ and the ‘*Explorers*’ share similar characteristics in the exploration and generation phases. Their cognitive styles showed moderate or diverse exploration of precedents and generation of ideas. However the *Selectors* generated slightly fewer numbers of ideas compared to the *Explorers*. The significant difference between them is the existence of the development phase. The five *Selectors* had the development phase with primary development. In contrast, the nine *Explorers* didn’t make any development for their ideas. Following sections provide a detailed explanation of each cognitive style.

6.3.1 Focused probers

One of the most distinctive characteristics of these focused probers is the highly focused exploration and generation of ideas. The range of probing relevant information is limited, and the utilization of the probed knowledge was highly focused on one or two ideas. Instead of investigating other possible solutions, the participants rather kept probing into the details of the idea. The examples of *Focused Probers*' cognitive maps clearly present the focused cognitive process (Figure 19). The cognitive maps represent the process of participants X-M2 and O-F1.

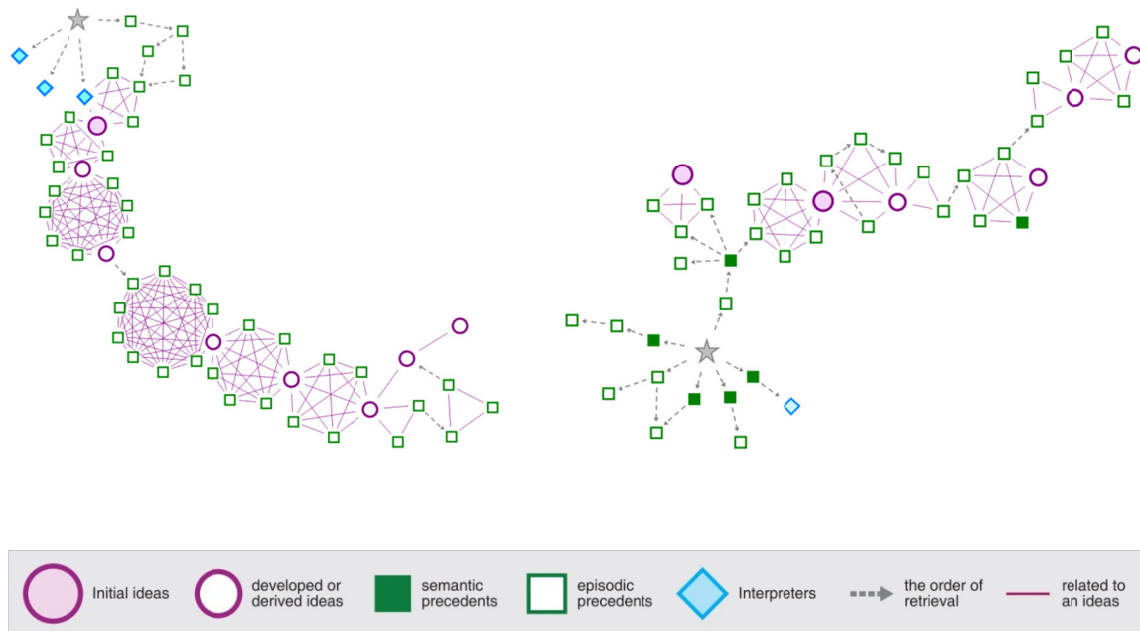


Figure 19 Cognitive maps of three Focused Probers – X-M2 and O-F1

Another notable characteristic of these types of designers is a high efficiency of associating prior knowledge with new ideas. Although they explored limited range of precedents, they efficiently utilized this retrieved knowledge to generate ideas. Compared to the other designers, a huge portion of their think flows is related to idea generation and development.

6.3.2 Treasure hunters

These types of participants are good at exploring a variety of precedents, but rarely produce ideas utilizing the precedents. Once they generated an idea, however, they refined it with details. The low productivity and high return resembles the property of treasure hunters. As shown in the Figure 20, the cognitive process of treasure hunters is composed of a long series of think flows related to an idea, and relatively many think flows which are not related to an idea. Each cognitive map belongs to the participant X-M1 and O-F6 respectively.

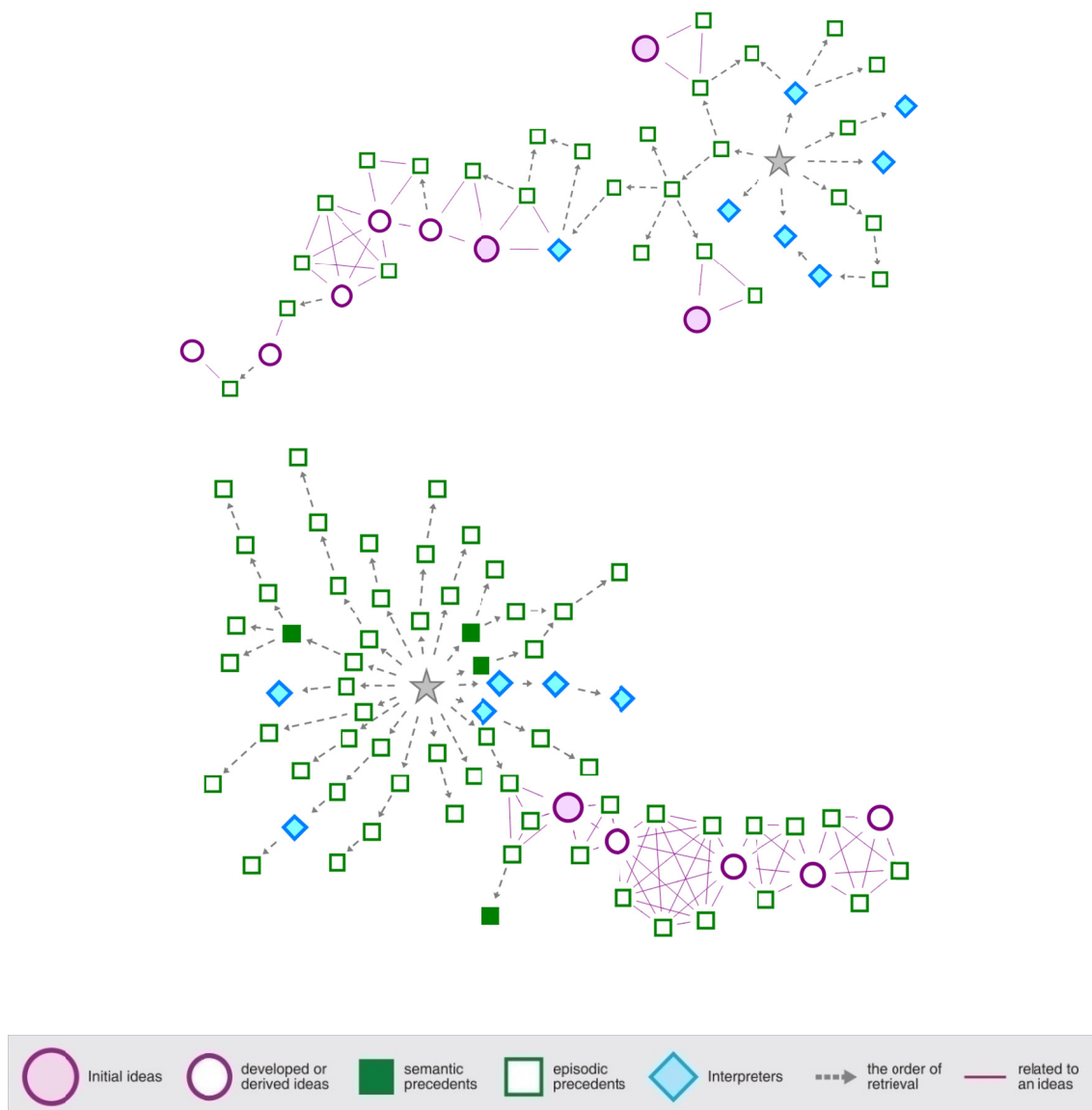


Figure 20 Cognitive maps of Treasure Hunters – X-M1 and O-F6.

Even though these designers developed one or two initial ideas with more details, the productivity of explored precedents is comparatively low in terms of producing distinctive ideas. If additional inputs or treatments are provided, some unutilized think flows may be able to produce a novel idea. The differences between utilized precedents and unutilized precedents could be investigated further to understand the creative moments and the way to facilitate divergent creativity.

6.3.3 Selectors

An outstanding characteristic of this cognitive style is selection process before entering the development phase. As shown in the Table 14, *Selectors* and *Focused Probers* utilized more precedents for evaluation of ideas compared to *Treasure Hunters* and *Explorers*. The evaluation of *Focused Probers* and *Selectors* was different because *Focused Probers* done evaluation while developing an idea, but *Selectors* evaluated candidate ideas to be developed further.

Table 14 The average proportion of precedents utilized for evaluation

	<i>Focused Probers</i>	<i>Treasure Hunters</i>	<i>Selectors</i>	<i>Explorers</i>
<i>Percentage of precedents utilized for evaluation</i>	6.30%	3.24%	5.98%	0.25%

Five participants, classified as *Selectors*, explored a wide range of topics, and generated various ideas based on the explored precedents. After the generation phase, they reviewed initial ideas and evaluated them according to their own criteria. Through the selection process, one or few ideas were chosen and selectively developed further. Figure 21 is a cognitive map of the two

selectors. In general, *Selectors* showed a divergent cognitive process, and had a few think flows which represent development of selected ideas.

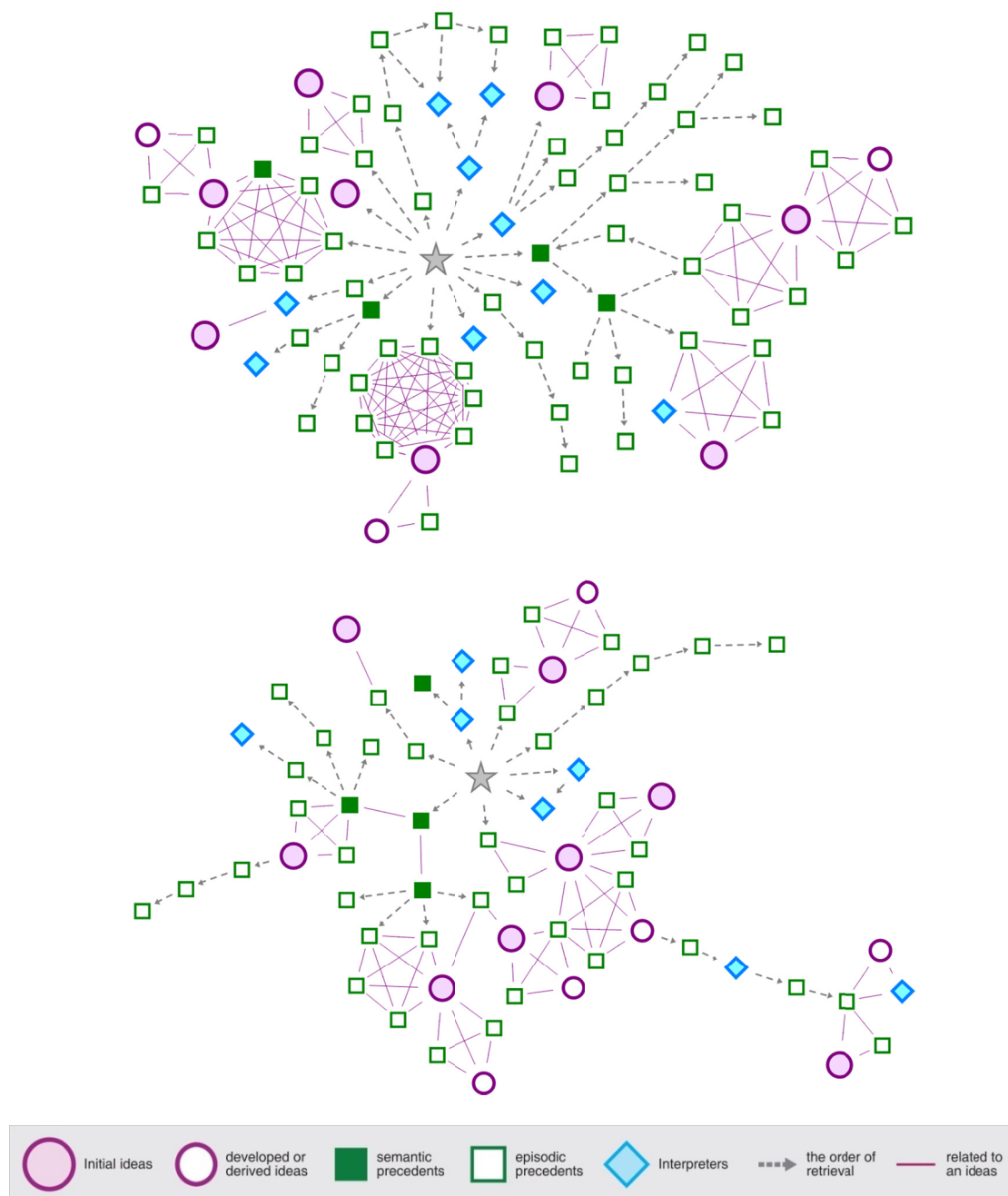


Figure 21 Cognitive maps of Selectors – X-F6 and O-M4.

The entire design process of selectors fits well to the general description of the design process – divergent thinking is associated with the early phase of design, and it becomes convergent as the solution is specified. This description has been accepted as a prototype of design process. However the result of this research suggests that the cognitive process of an individual may differ from the prototype. It could be a general design process of a design team or a company, but each individual designer may have a different cognitive process to do design. The result of this study also supported the diversity of the cognitive process.

6.3.5 Explorers

Unlike the previous three cognitive styles, *Explorers* didn't have any development phase to refine and improve their initial ideas. The entire cognitive process is composed of the exploration of various topics, and the utilization of them. The diversity of explored precedents and generated ideas is well represented in the cognitive maps of the two *Explorers* (Figure 22). The utilization of explored precedents is efficient enough to maintain the diversity of generated ideas as much as the explored topics.

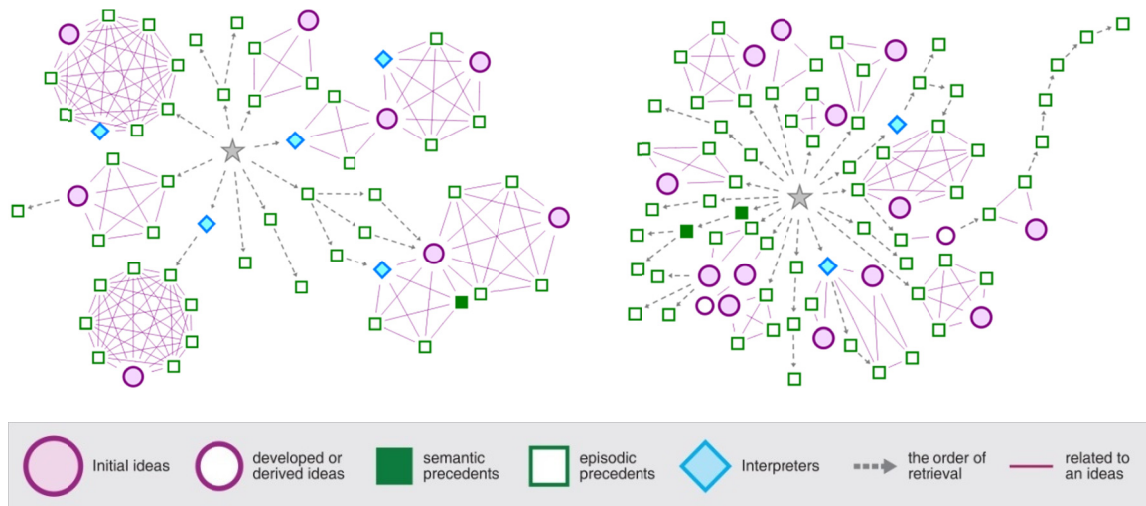


Figure 22 Cognitive maps of explorers – O-M2 and O-F4

Throughout the entire design process, *Explorers* kept exploring their prior knowledge and experiences for new and original ideas. In a few cases, they reviewed their prior ideas as the selectors did. But the purpose of reviewing was different with the one of selectors. The selectors reviewed previous ideas for evaluation, but explorers review them for discovering an uninvestigated solution space. The cognitive style of explorer presents a striking contrast with the one of focused probers. The cognitive process of focused probers is mainly composed of convergent thinking which is focused on a solution. On the other hand, the cognitive process of explorers consists of continuous divergent thinking to generate novel ideas.

7 Differences of the cognitive styles

In this section the differences among the cognitive styles will be discussed in terms of the idea generation and utilization of precedents throughout the creative process. Because the cognitive styles were determined based on the factors related to the cognitive activities, the significant differences were expected in the idea generation process. A statistical analysis was done to investigate the differences more precisely. As same as the section 5.1, the numbers of think flows, initial ideas and developed ideas were compared as representative factors of the creative activities. In order to identify differences in utilization of precedents, the proportions of precedents were analyzed depending on the memory type and the role in the creative process.

7.1 Differences of cognitive styles in idea generation

A one-way ANOVA was run in order to examine the differences of the cognitive styles in creative activities related to the idea generation. The numbers of think flows, initial ideas and developed ideas were assigned as dependent variables. Table 15 shows the average number of these three values depending on the cognitive styles. There were statistically significant differences among cognitive styles in all three values – the number of think flows ($F(3, 20) = 3.717, p = .028$), the number of initial ideas ($F(3, 20) = 27.252, p < .001$), and the number of developed ideas ($F(3, 20) = 24.103, p < .001$).

Table 15 The average number of think flows and ideas depending on the cognitive styles

	Number of think flows*		Number of initial ideas*		Number of developed ideas*	
	Mean	SD	Mean	SD	Mean	SD
<i>Focused Probers</i>	12.50	2.26	1.17	0.41	4.83	2.32
<i>Treasure Hunters</i>	21.75	6.99	2.50	1.29	5.00	0.82
<i>Selectors</i>	24.80	9.36	9.00	2.12	2.20	0.84
<i>Explorers</i>	21.78	6.72	11.33	3.39	0	0

*. The mean difference is significant at the .05 level.

A Tukey post-hoc test revealed that the number of think flows of *Focused Probers* was significantly less compared to *Selectors*. There were no statistically significant differences among *Treasure Hunters*, *Selectors*, and *Explorers*. It suggested that *Selectors* retrieved and explored distinctively many topics during the creative process. In contrast, *Focused Probers* investigated fewer topics as their name indicates.

In the case of the number of initial ideas, a Tukey post-hoc test reported that *Focused Probers* and *Treasure Hunters* generated statistically significantly fewer ideas compared to the *Selectors* and *Explorers*. There were no statistically significant differences between *Focused Probers* and *Treasure Hunters*, as well as between *Selectors* and *Explorers*. As described in the method of determining the cognitive style in the generation phase, *Focused Probers* and *Treasure Hunters* were participants who showed a limited diversity in generating of ideas. Contrary to them, *Selectors* and *Explorers* showed an active generation of ideas. The result of post-hoc test supported the significant difference between these two groups in terms of generating solutions.

In terms of the number of developed ideas, four cognitive styles were significantly different with each other except the *Focused Probers* and *Treasure Hunters*. These two styles were not statistically different in developing their ideas.

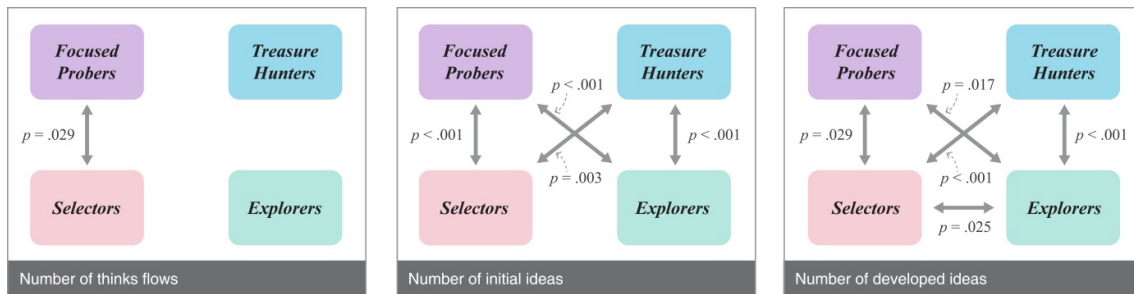


Figure 23 A summary of the post-hoc Tukey test – differences among four cognitive styles in idea generation

Figure 23 shows the summarized result of one-way ANOVA. The arrows mean differences with statistical significance and the numbers with the arrows indicates the p value. The result suggested that the difference in the diversity of explored topics is not that meaningful except the difference between *Focused Probers* and *Selectors*. *Focused Probers* and *Treasure Hunters* were not distinguishable in terms of idea generation process. However others were distinctively different in generation and/or development of ideas with each other.

7.2 Differences of cognitive styles in utilization of precedents

Contrary to the distinctive differences in idea generation and development, there was no significant difference in utilization of precedents among four cognitive styles. As shown in the Table 16, the proportion of utilized episodic precedents is gradually increased from *Focused Prober* to *Explorers*. However, a one-way ANOVA revealed that there was non-significant difference among cognitive styles in the proportion of episodic precedents and semantic precedents.

Table 16 The average proportion of utilized precedents depending on the cognitive styles

	Episodic precedents		Semantic precedents	
	Mean	SD	Mean	SD
<i>Focused Probers</i>	87.04%	8.71	12.97%	8.71
<i>Treasure Hunters</i>	90.89%	10.40	9.11%	10.40
<i>Selectors</i>	93.22%	1.94	6.78%	1.94
<i>Explorers</i>	93.70%	6.06	6.30%	6.06

There was no significant difference among cognitive styles in utilizing precedents as well. Table 17 shows the average proportion of precedents depending on their roles in the creative process. The utilization for synthesis and evaluation showed p value near .05, but it was not enough to differentiate four cognitive styles with each other. In the creativity research field, there was a study which reported that assimilative people perform better with episodic experiences and explorative people performed better with more general experiences (Martinsen, 1995). However, the result of this study had no indication of different utilization of knowledge depending on the cognitive styles although the performance of each participant was not assessed.

Table 17 The average proportion of precedents utilized for analysis, synthesis, and evaluation

The role of precedents	Analysis of the problem space		Analysis of the solution space		Synthesis		Evaluation	
	Mean	SD	Mean	SD	Mean	SD	Mean	SD
<i>Focused Probers</i>	6.57%	7.46	25.31%	17.12	59.97%	16.21	6.30%	5.43
<i>Treasure Hunters</i>	30.27%	19.85	25.06%	9.49	41.44%	23.09	3.24%	3.82
<i>Selectors</i>	14.08%	12.87	38.58%	11.18	39.70%	7.07	5.98%	4.61
<i>Explorers</i>	13.55%	11.74	23.35%	13.34	63.03%	15.70	0.25%	0.74

It was interesting that the precedents utilization was not statistically different even though each cognitive style showed distinguishable activities in exploring, generating, and developing ideas. This indicated that the participants could generate a different number of ideas while utilizing the same type of precedents for same purpose. In other words, the creative outcomes maybe influenced by the individual style of a designer not by the type of precedents and their application. Thus it could be concluded that assigning designers with appropriate cognitive styles is much more effective to obtain a desired outcomes than providing relevant information for designing.

This result implies the importance of understanding the cognitive styles of designers. It becomes more evident comparing to the effect of constraints. As shown in the Table 18, the level of constraints had no significant effect on the outcomes of creative activities. However participants behaved differently in generation and development of ideas. The differences defined the cognitive styles of designers. On the other hand, the cognitive styles had no differences in utilization of precedents, while the level of constraints differentiated it.

Table 18 The effect of constraints and cognitive styles on the creative process

	Outcomes of creative activities	Utilization of precedents
<i>Constraints provided by the design brief</i>	Non-significant effects	Significant effects
<i>Cognitive styles</i>	Significant relationships	Non-significant relationships

Based on the result I could conclude that the intrinsic properties of designers have a strong relationship with the creative outcomes rather than the external conditions. Designers may change the usages of prior knowledge and experiences depending on the problems that they are dealing with. The cognitive style is unchanged, however, while they utilize different type of precedents for different purposes.

7.3 Implications on design education and practice

The results of this research indicate the importance of understanding the cognitive styles of designers. Thus this supports the work of other researchers to indicate cognitive style as critical to the application on the kinds of experiential and tacit knowledge employed during design practice (Brophy, 2001; Cross, 1985; Self, Evans, & Dalke, 2014; Tovey, 1984). Differences in the cognitive style imply differences in perceiving, interpreting and solving design problems. This research has shown that each cognitive style could be varied in its creative outcomes which were related to the diversity of ideas and the degree of development. In this regard, understanding the cognitive styles of designer may have more pragmatic implications for both design education and design practice.

Design education is required to provide appropriate educational programs for each student in order to promote students' expertise and distinctive abilities. Cross (1990) has mentioned that design ability can be developed and improved to the mature level through design education. Thus appropriate design education is crucial to nurture skilled designers who possess distinguishable abilities. If a design student naturally has a cognitive style and a better ability to conduct a certain type of thinking, the education should be different with others who have another type of cognitive style. The education should be able to identify the cognitive style of each student, and support them to promote their innate characteristics. Not only the curriculum but also the teaching strategies should be matched to the cognitive style of students. The interactions of cognitive styles between teachers and students can cause significant differences on the result of learning (Felder & Silverman, 1988; Pask & Scott, 1972). Therefore, understanding the cognitive style of both teachers and students is required to enhance the effect of instruction and learning, and provide better education.

In design practice, understanding the cognitive styles of designers became much more important. Although industrial and product designers learnt from the concept design to detailed design, the real design process or the product development process of a company is a collaborative work with designers, engineers, marketers, etc. (Pahl, Wallace, & Blessing, 2007; Ulrich & Eppinger, 1995). Designers are usually allocated to the certain stage of the design process instead of managing the entire procedures. Depending on the stage that designer are involved, the design tasks are changed, and the preferred cognitive styles are also different. If a firm had identified the cognitive styles and abilities of designer in advance, the firm can allocate appropriate designers to suitable design tasks. It is expected to contribute to the improvement of efficiency and quality of the outcome as well. The identification of cognitive styles may also provide useful information to construct a better design team. In this regard, further investigation is required to understand the specifics of each cognitive style, and suggest a method to identify and promote the cognitive style in a constructive way.

8 Conclusions

In the discipline of psychology and design, prior knowledge and experiences have been regarded as an essential factor which supports the creative process as well as inhibits it. Though many researchers have argued the importance of prior experiences, few researches was found in the field of product design with empirical data. In this regard, this research aimed to examine the cognitive process of designers in terms of the utilization of prior knowledge and experiences.

I utilized two design briefs which hold different amount of constraints based on the hypothesis that the level of constraints may affect to the creative process. Twelve out of 24 participants utilized a design brief with fewer constraints, while others received a brief with greater constraints.

The verbal protocols of participants were firstly segmented into a unit of a discrete think flow. Then the segmented protocols were encoded. The main content of the coding scheme was precedents – prior knowledge and experiences. Two different classifications of precedents were applied. The first was related to the memory type - episodic and semantic - which was defined based on the theory of memory structure. A second related to the role of precedents in the creative process – analysis, synthesis, and evaluation – which was derived from the model of design process.

The encoding results suggested that the level of constraints had significant effect on the utilization of precedents. In the more constrained problem, designers tended to utilize more semantic precedents. However, there was no significant effect of constraints on the creative outcomes such as the number of ideas. Regardless of the design brief, all participants displayed a dominant use of episodic precedents.

For further analysis of the encoded protocols, a new way of graphical representation was devised, which was named as a cognitive map. It visualizes the creative process of designers in

terms of utilization of precedents, and provides a comprehensive look of their cognitive activities. Through analyzing the cognitive maps of 24 participants, three different phases of the creative process were identified which were exploration, generation, and development phases. The holistic cognitive style was determined through integrating the cognitive styles of three phases. As a result, four cognitive styles were defined. – *Focused probers*, *Treasure hunters*, *Selectors*, and *Explorers*. Further, statistical analysis revealed that these four cognitive styles had significant differences in the creative outcomes, but non-significant difference in the utilization of precedents.

The results suggest that the intrinsic cognitive style has a stronger relationship with the creative outcomes rather than the external constraints that designers should manage. This emphasized the importance of understanding cognitive styles for better design education and practice. Design education should be able to identify the innate styles of students, and provide appropriate instructions to promote the inherent abilities. This has potential to facilitate the performance of designers in the practice by allocating them with suitable tasks and improving their required skills.

In conclusion, this research investigated the cognitive processes of designers from the perspective of utilization of precedents. It was identified that there were four different cognitive styles in exploring precedents, and generating ideas with precedents. The characteristics and differences of the four cognitive styles were reviewed and discussed as well. To learn more about the nature of each cognitive style, however, further studies are required especially on the other aspects of cognitive process which were not investigated in this study. It can provide a richer and better understanding of each cognitive style in order to identify styles and promote them. Further study should be conducted on the method which helps the identification of cognitive styles in easier way as well. If a simple but reliable way of identifying cognitive styles is developed, it can suggest applicable guideline for both design education and practice.

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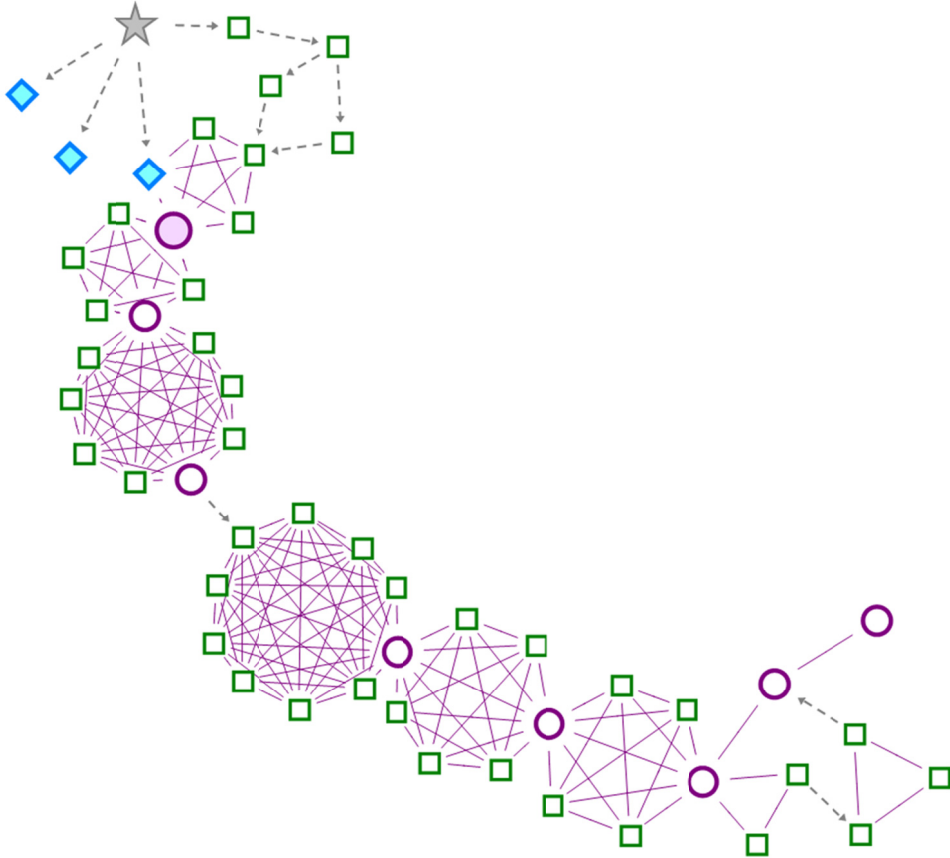
APPENDIX

Cognitive maps of 24 participants

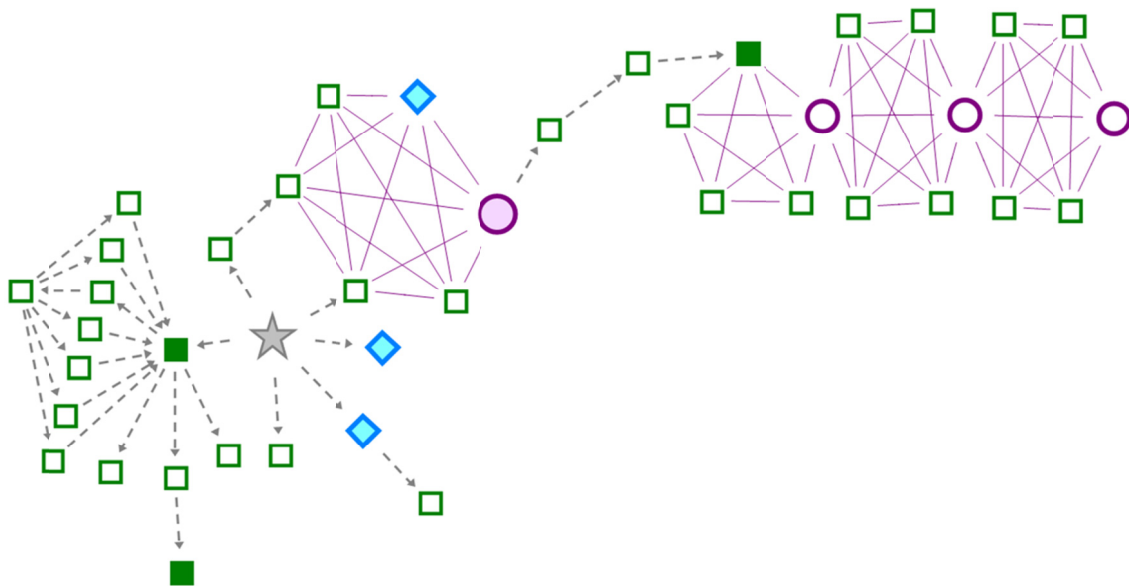
Cognitive Style	Participants	Number
<i>Focused Probers</i>	X-M2, X-M5, X-F4, O-M3, O-M5, O-F1	6
<i>Treasure Hunters</i>	X-M1, X-F5, O-F5, O-F6	4
<i>Selectors</i>	X-M6, X-F6, O-M1, O-M4, O-F3	5
<i>Explorers</i>	X-M3, X-M4, X-F1, X-F2, X-F3, O-M2, O-F2, O-F4, O-F7	9

Focused Probers

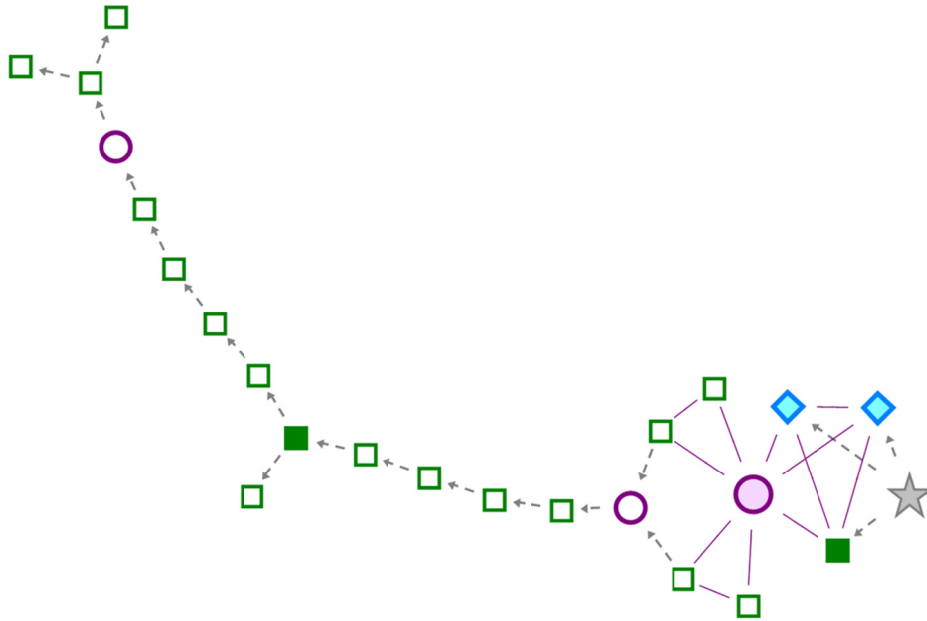
X- M2



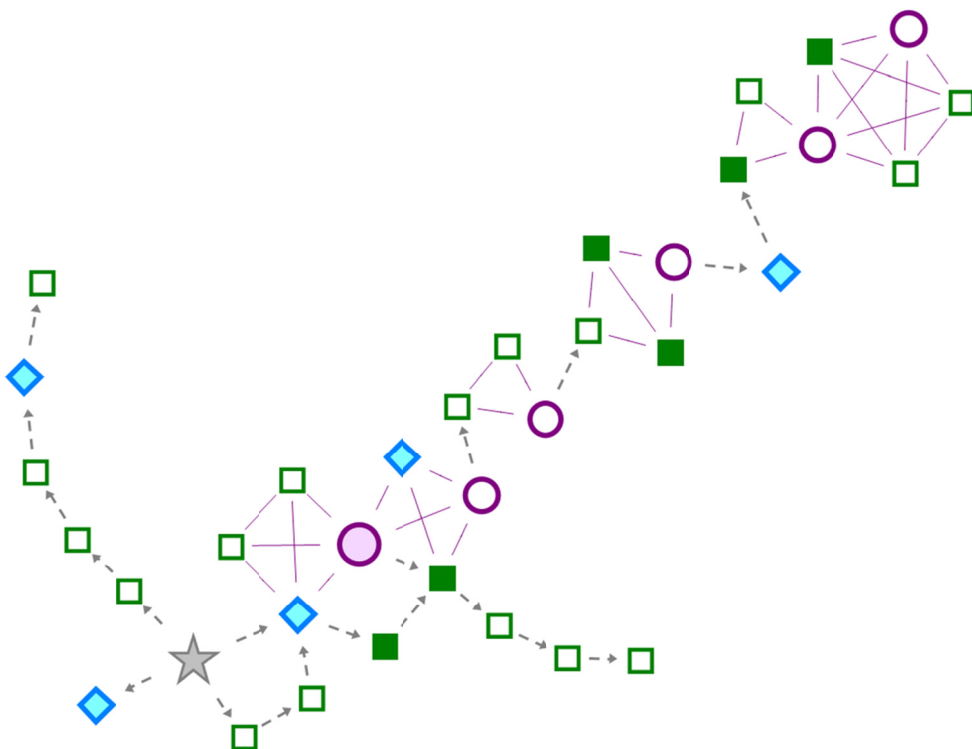
X-M5



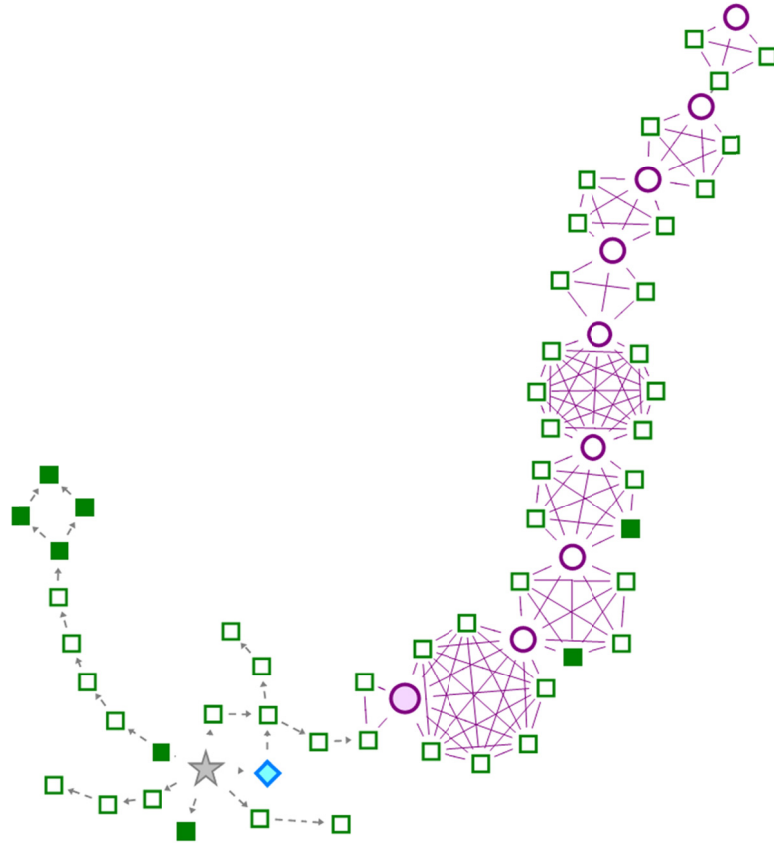
X- F4



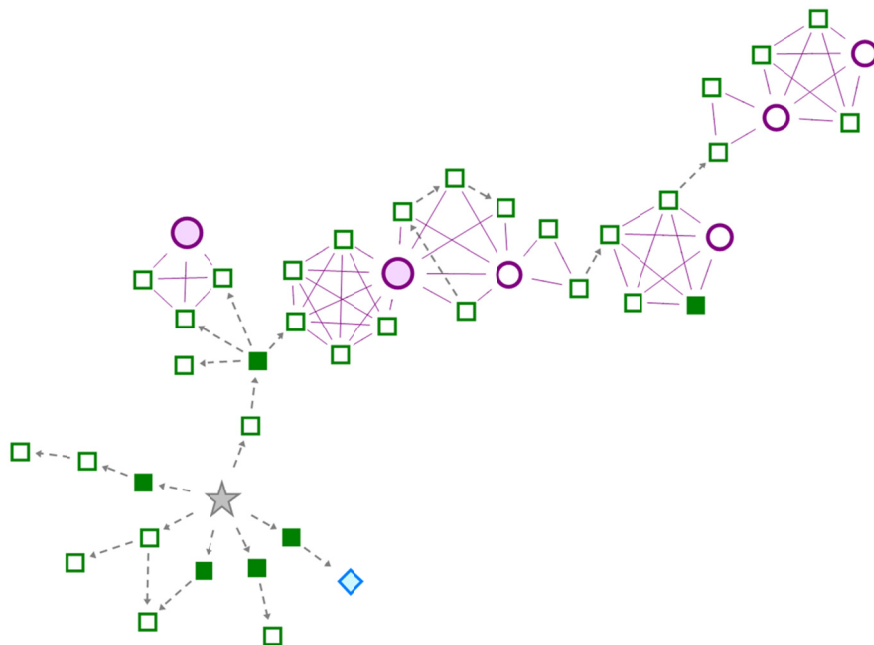
O-M3



O-M5

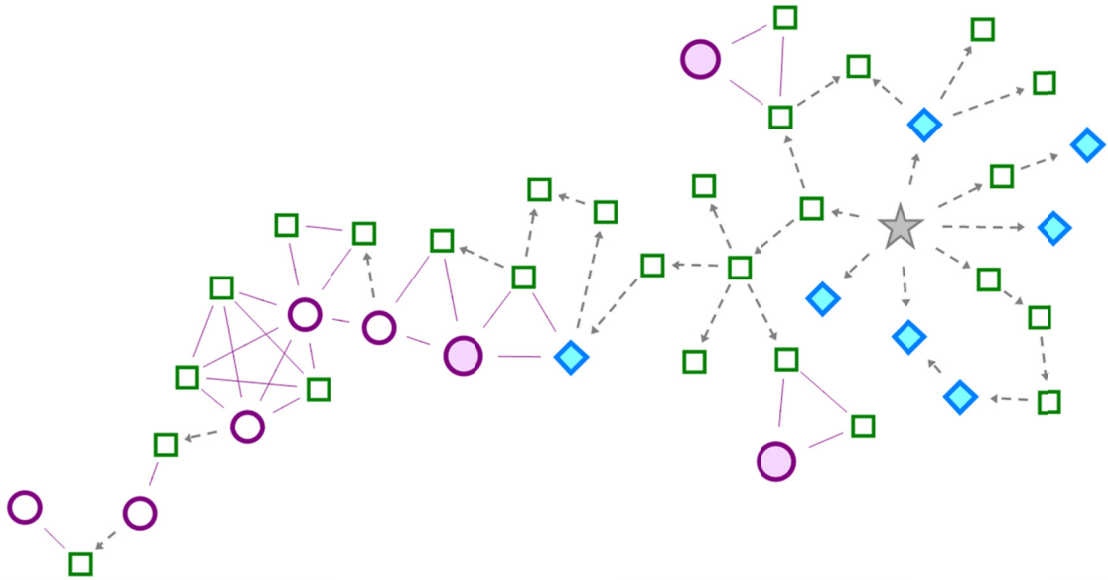


O-F1

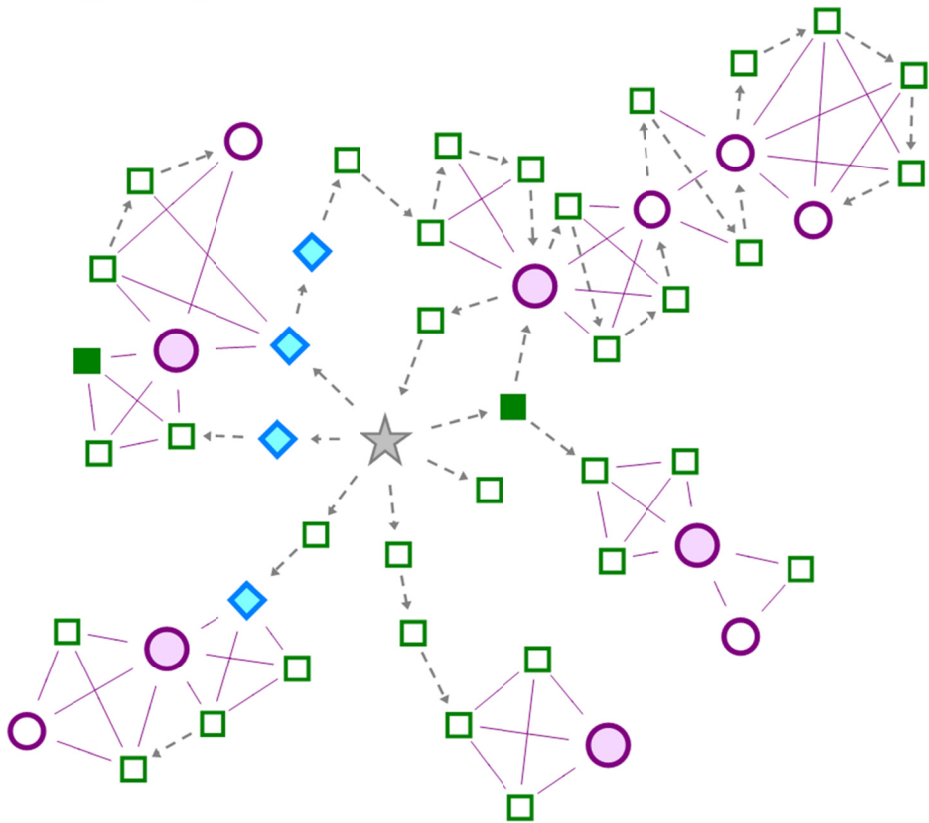


Treasure Hunters

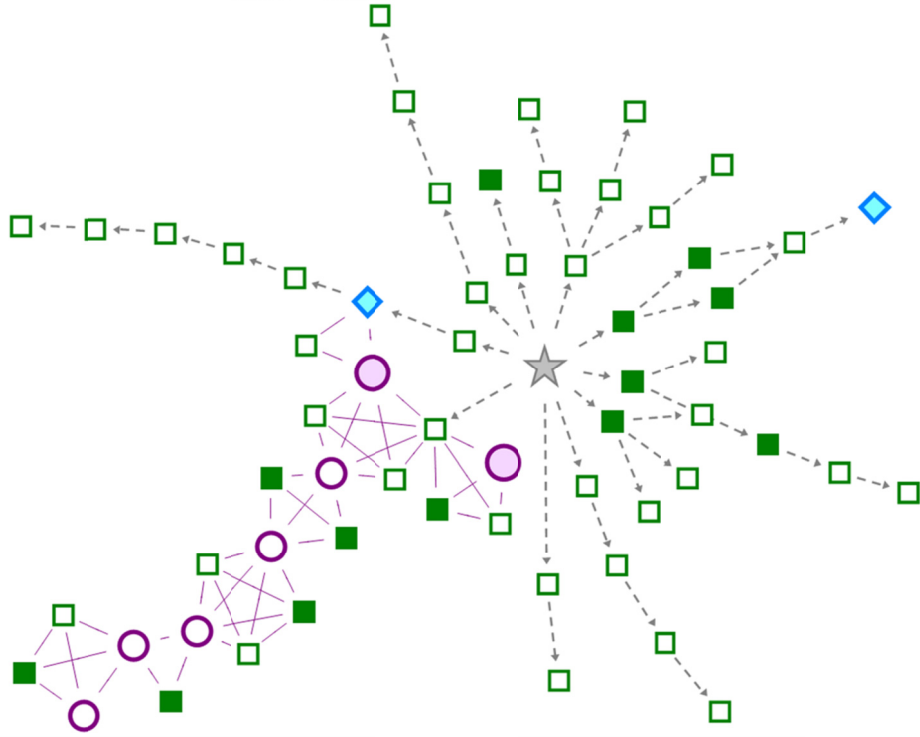
X-M1



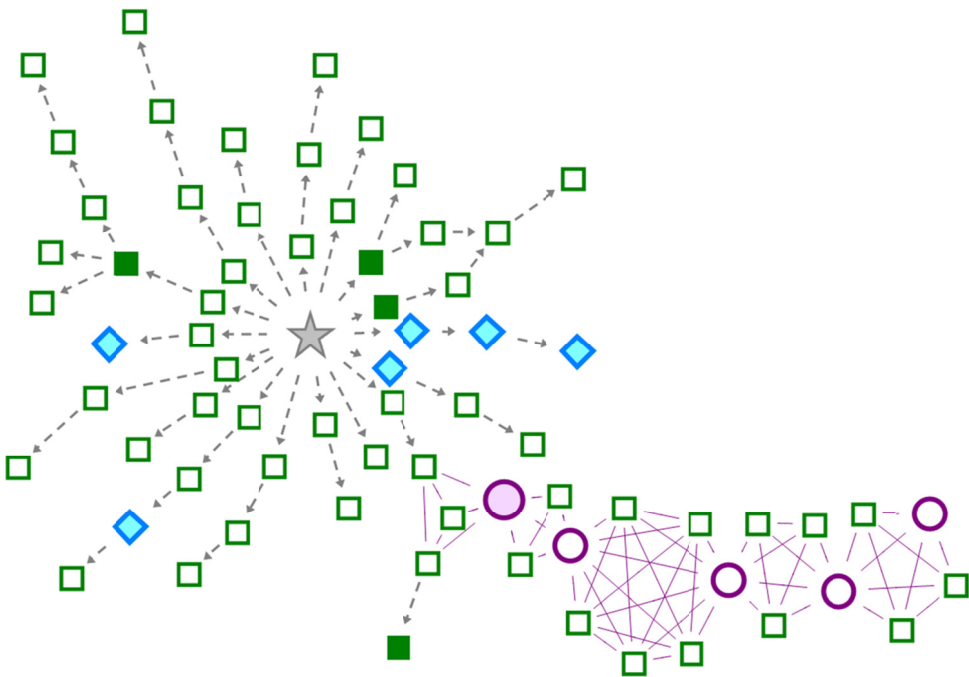
X-F5



O-F5

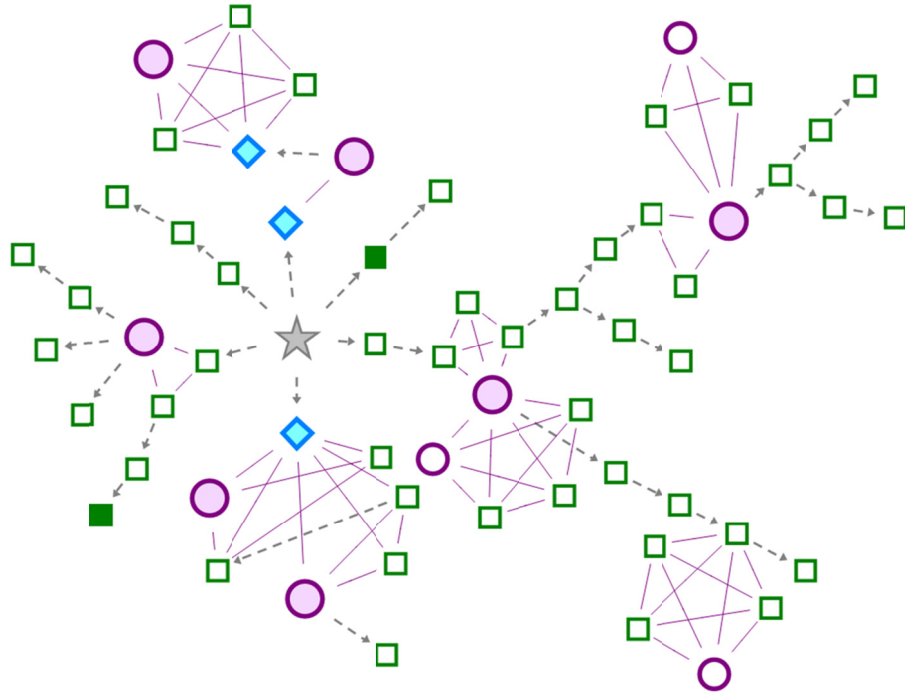


O-F6

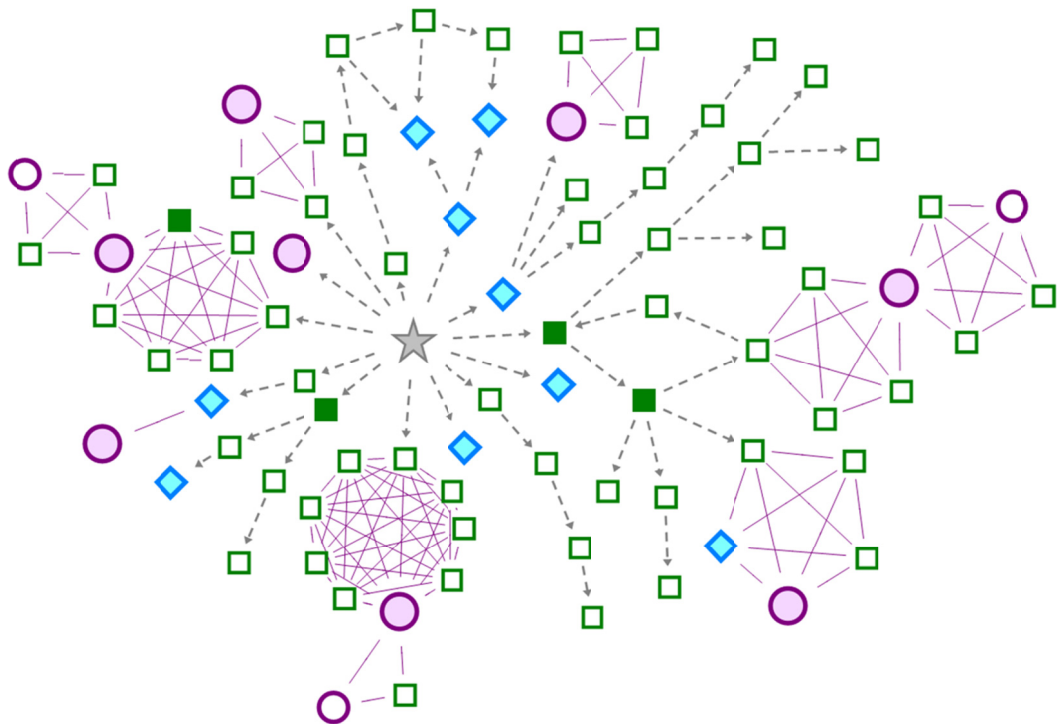


Selectors

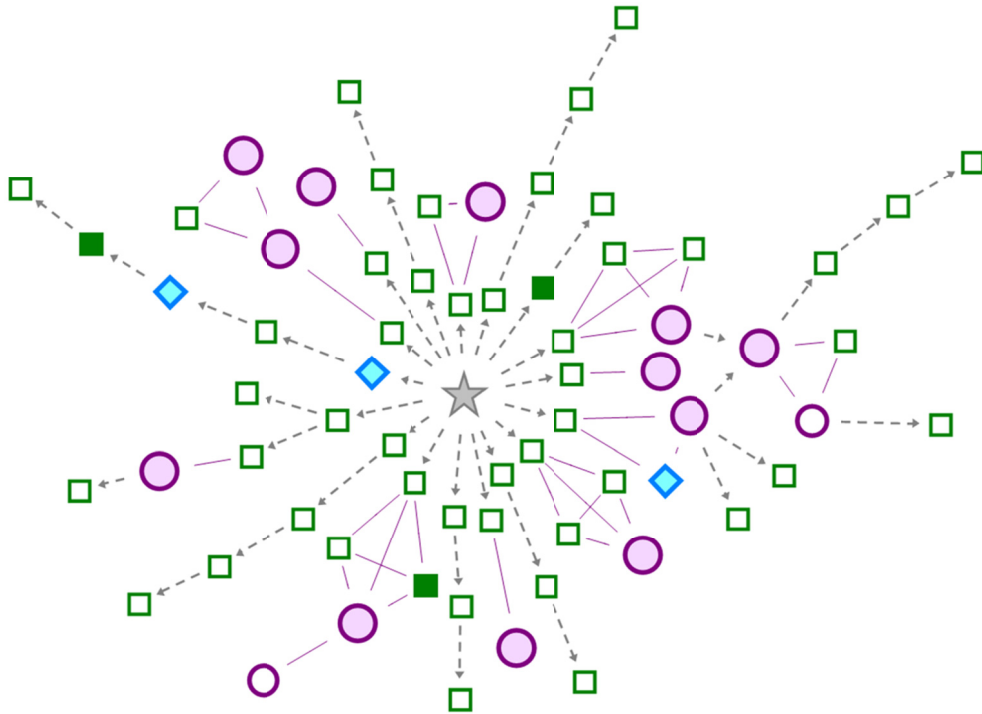
X-M6



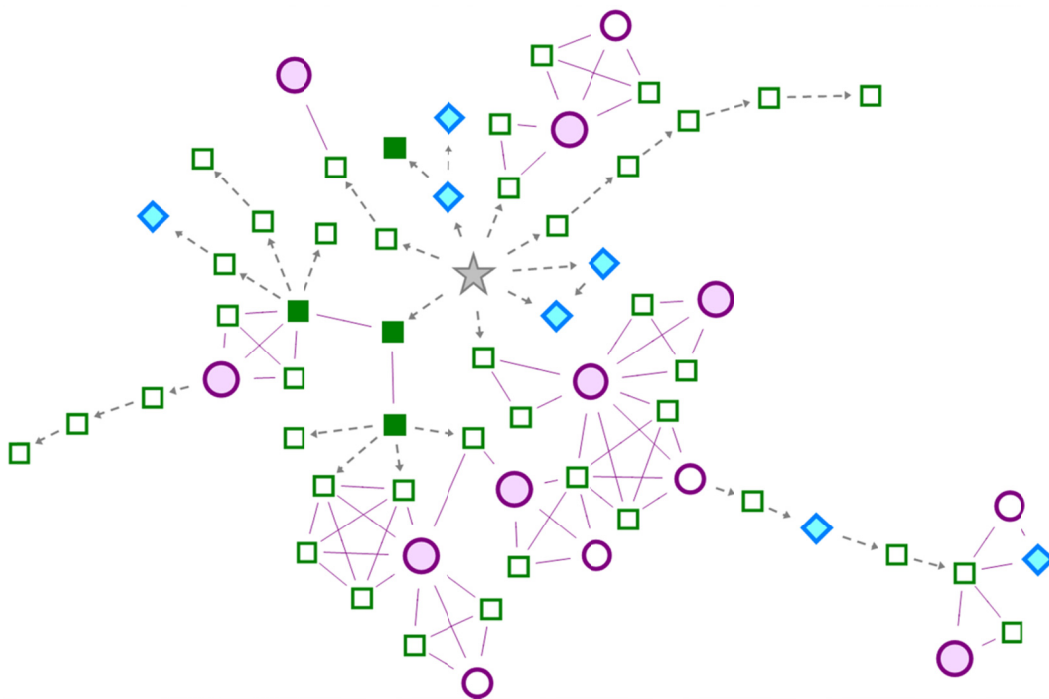
X-F6



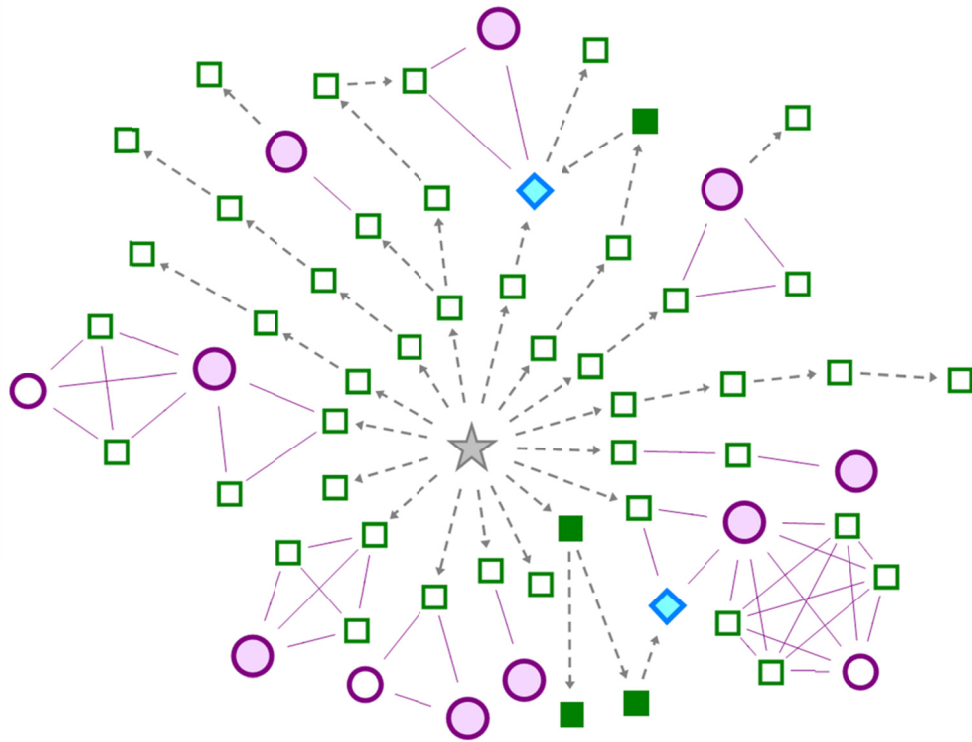
O-M1



O-M4

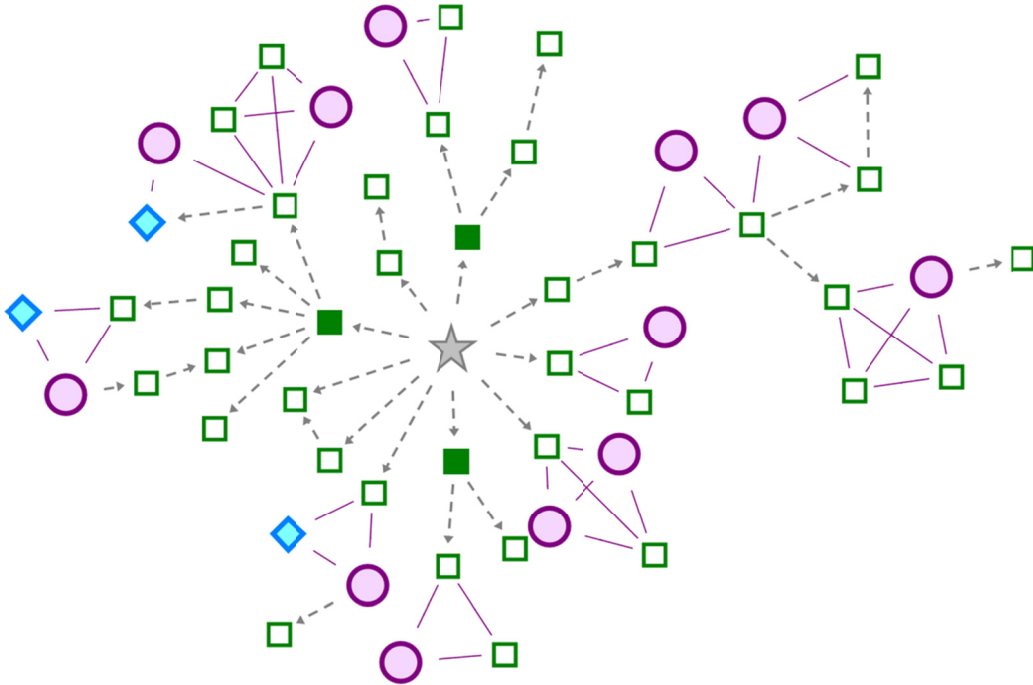


O-F3

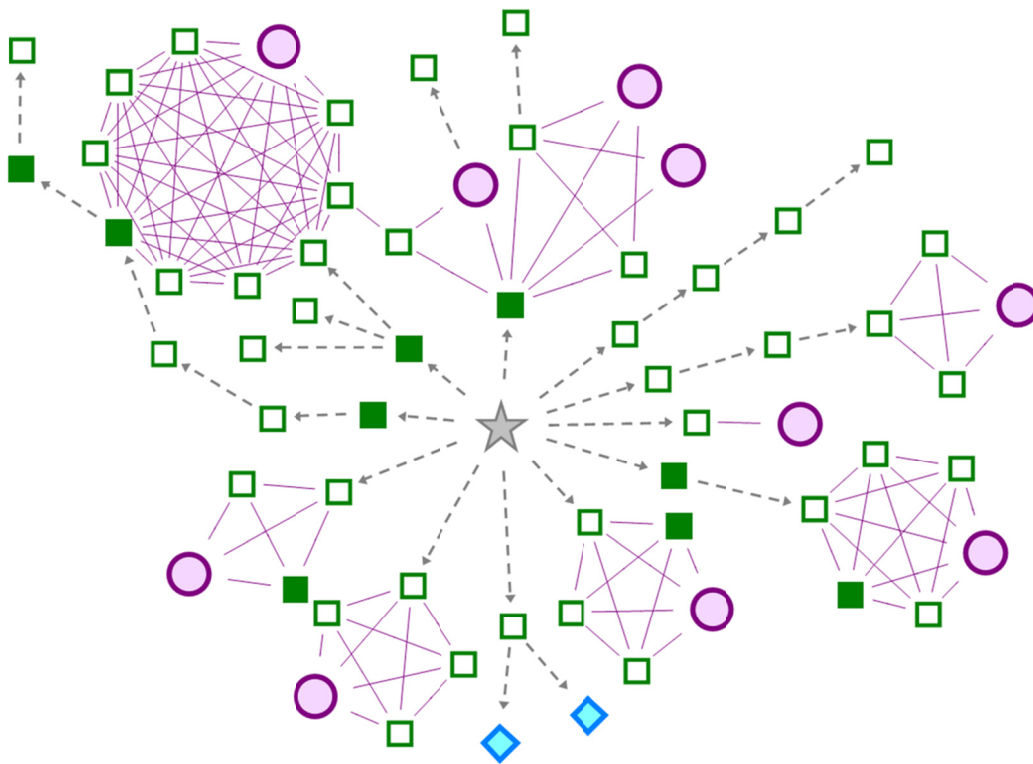


Explorers

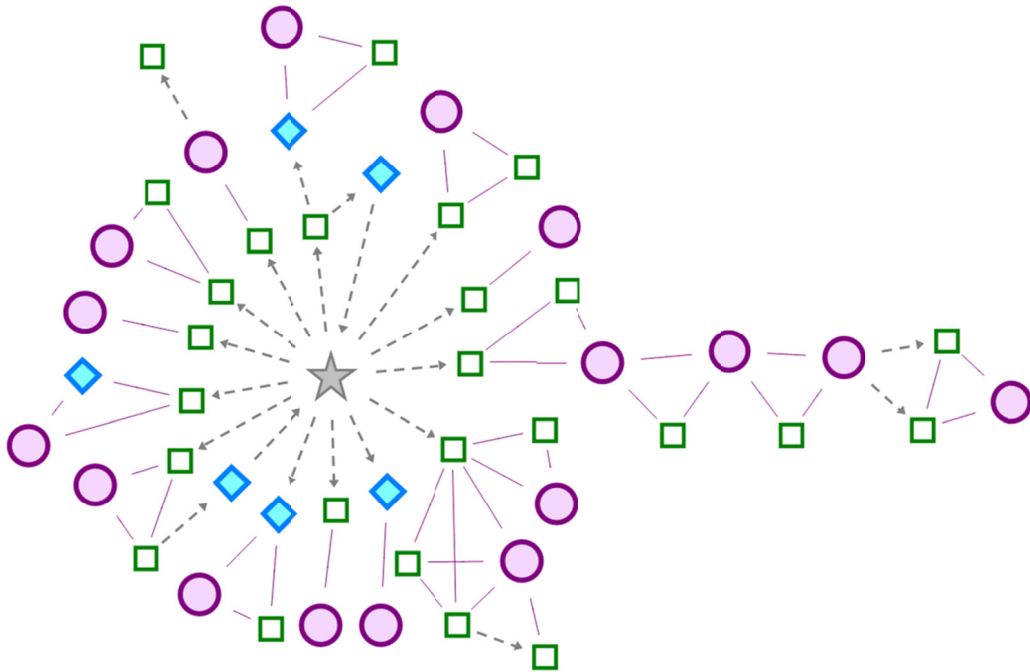
X-M3



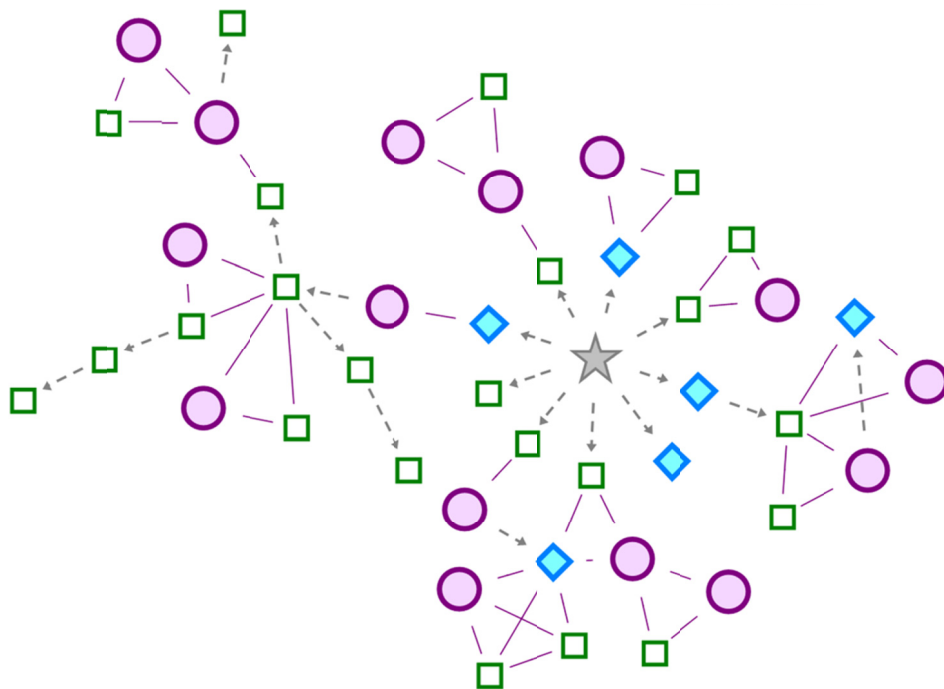
X-M4



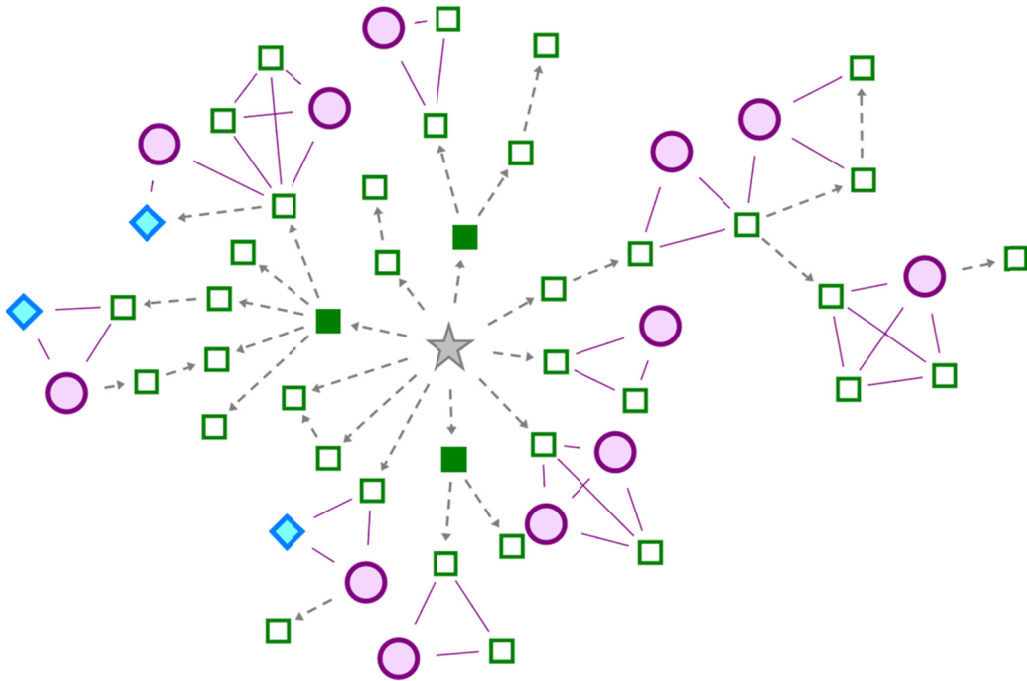
X- F1



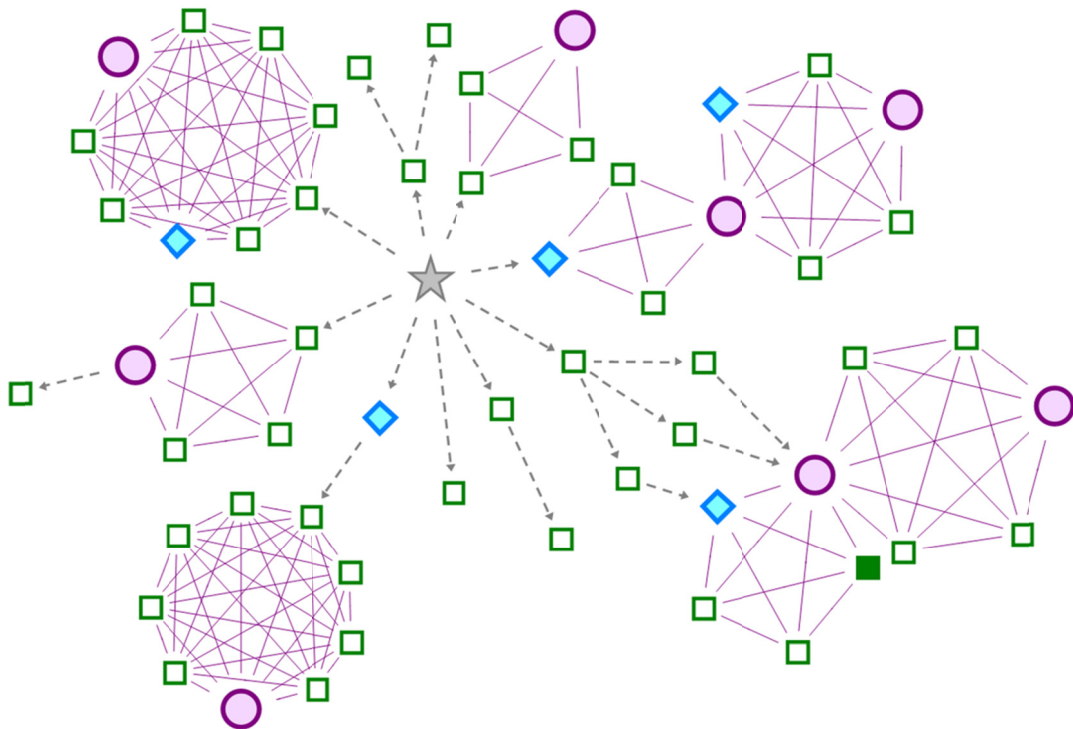
X-F2



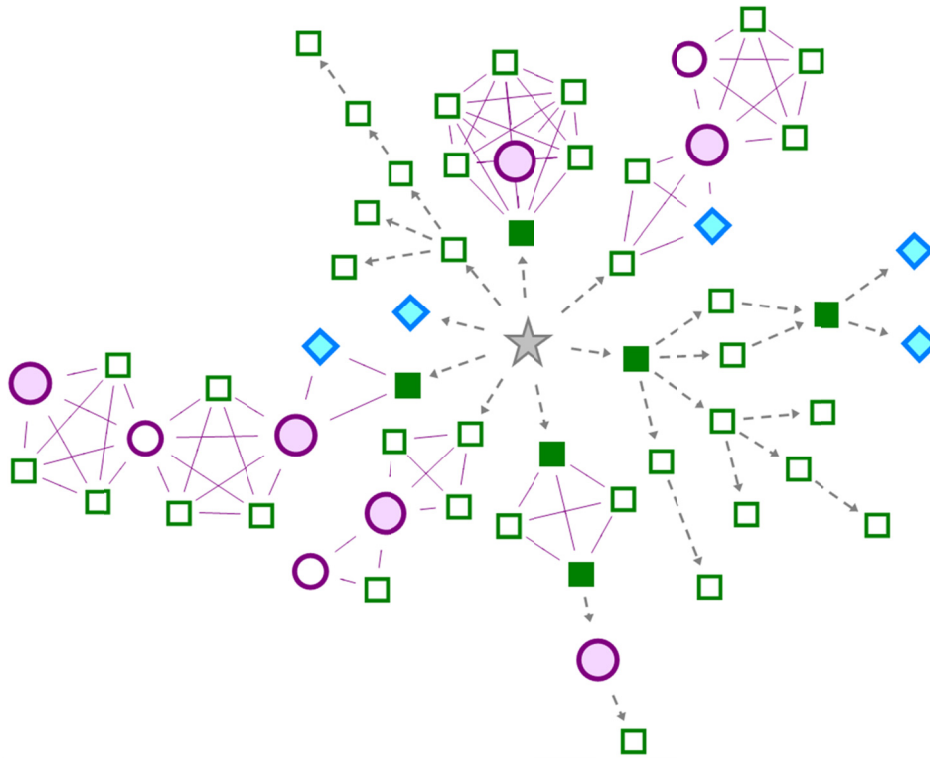
X- F3



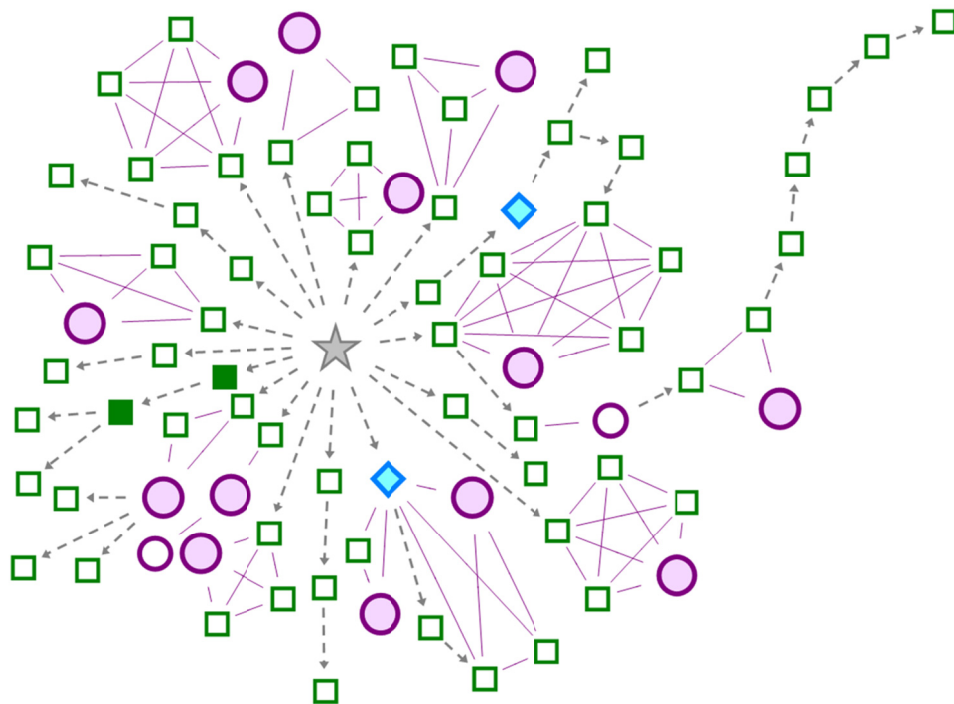
O-M2



O-F2



O-F4



O-F7

