The structure of patterns

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This paper aims at learning more about the structure of patterns by examining a very simple and intuitive example of a pattern: a path as a solution to reach a goal. A path is obviously bound to its environment and this happens to be a good starting point to emphasize why the context of a pattern is so important. By visual illustration one will find that it is the environment with its embedded forces that shapes the possible solutions. On a map this relation can literally be seen. Paths and their representations on maps are very well known concepts. This allows the use of common sense to understand properties of patterns that are otherwise hard to grasp. The difference between patterns of things in the world and their description as patterns becomes clearer.

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1. INTRODUCTION

Design patterns are well established in the domain of software. Other disciplines, such as human computer interaction (Borchers, 2001; Tidwell, 2005; Schümer & Lukosch, 2007), web design (Van Duynie, Landay, & Hong, 2004; Mahemoff, 2006; Scott & Neil, 2008; Malone & Crumlish, 2009), management and organization (Harrison & Coplien, 2005; Rising, & Manns, 2005) or pedagogy (Anthony, 1996; Bergin, 2001; Demtl, 2006), have adopted the pattern concept.

Since all disciplines strive for the discovery of general rules, laws or patterns it is sometimes hard to explain what is unique in the approach taken by the pattern community and the ideas based on Christopher Alexander. Terms such as “context”, “forces”, “problem”, “consequences”, “diagram”, or “interaction” have particular meaning and dependencies in this approach. I have found it helpful to use proven paths in a territory to explain how patterns capture, describe and explain good practices. A path is an example of a solution that leads to a specified goal and it is a simple concept that is very well known to everyone. This simplicity enables us to show how the territory and the overall situation define which paths are potential solutions and which properties each path has.

Pattern sceptics very often do not understand what is innovative about the pattern format. Best practices have been documented for a long time and scientific discovery is all about finding invariants – patterns – in nature. While that is true, the elaboration in the pattern format does not only describe recurrent forms but reasons about the form in terms of forces and consequences. Most people agree that a solution has to be adequate for the task at hand. However, many descriptions that do not follow one of the pattern formats lack this context information. The purpose of this paper is to use a metaphor to address common sense. Nobody would follow directions that belong to a different landscape. Nobody is happy about directions that are too abstract (e.g. missing one or two turns) or too detailed (e.g. describing every stone of a path). Nobody would follow directions unless they make sense, i.e. it should be reasoned why one should follow a path. Yet many descriptions of solutions do not provide this information. They are too abstract or detailed and fail to explain why a form solves a given problem. Patterns, on the other hand, do capture contexts, forces, consequences and solutions at a medium level of abstraction.

Pattern beginners who are willing to share their knowledge by writing patterns will see that it takes more than just knowing a proven path to describe a reusable solution. Once we are aware of something that has...
worked several times we are eager to write it down. But it is much harder to write down why something has worked and to reason under which circumstances the configuration will work or fail. The path metaphor hopefully shows that it is worth the effort. By explaining a solution form along with the fitting environment and what has shaped the solution we can help the user to understand the form and make sense of it. In order to adapt a pattern to a specific situation one should know what has influenced the general solution.

Pattern experts can use the visualizations to discuss their conceptions about patterns. Both agreement and disagreement will give new insights to how we see patterns. Since human beings are very good at perceiving visual patterns, some properties of recurrent structures might be grasped more intuitively, e.g. how patterns can be divided into sub pattern, how patterns overlap and how patterns work together. Most important, the path metaphor helps to teach the core concepts to interested novices and convinces sceptics of the value that the pattern format offers.

2. A BASIC DEFINITION

Let us begin with Christopher Alexander’s definition of patterns in A Pattern Language (1977):

“.Each pattern describes a problem which occurs over and over again in our environment, and then describes the core of the solution to that problem, in such a way that you can use this solution a million times over, without ever doing it the same way twice.” (Alexander, 1977)

There are two parts of this definition that are essential to patterns:

1. a pattern is the solution to a problem in an environment
2. the form of the solution can be used over and over again without ever doing it the same way twice

Both statements, simple as they may appear, are rich in their meaning. Let us therefore consider a familiar environment, a hillside landscape, to explore the concept of patterns. In such an environment, if we intend to hike from one place to another, we may encounter the problem that we cannot directly move in a straight line to the destination because we cannot cross canyons or pass over steep walls. Each trail that guides us to the destination is therefore a solution to our problem: getting us from where we are to our desired destination.

![Fig. 1. Context, Problem, Forces and Solution in a hillside landscape](image)

Problem:
You need to reach the destination, but a direct path is not possible due to obstacles…

Forces:
Finding a path to the destination requires you to consider these forces:
- rock faces require climbing equipment
- slippery hills are exhausting and dangerous
- you need to refill your drinks at some point
- canyons cannot be crossed
- you have a limited endurance.

Context:
In a particular environment…
...you are here and…
...this where you want to be.

Solution:
This path is a proven solution (that actually guides you to your goal).
3. UNDERSTANDING CONTEXT

The context is the environment or the situation in which we find ourselves in. In the simple example of a hike, the context is the physical environment of the landscape as well as your current situation (where you are, how well trained you are, what your hiking skills are, which tools you have at hand etc.) and your goal or intent. Besides reaching your final destination, your intention may be to find ways that are not too tiring or to find ways that are physically challenging. You may prefer a path along scenic views or cultural attractions and make this a requirement for the solution.

The context depends to some extent on your personal intent and preferences while at the same time the environment – the hills, canyons, slopes, lakes, cabins - is out of your hands.

At first glance, the context of that landscape seems to be fixed and static. However, the context can vary. One can hike at different times of the year; there will be different animals that cross the path, and there may be different groups of people who take the same trail. Hence, there is a certain degree of variability in the context. The power of a pattern is that it is open enough to be adapted to specific needs of an actual situation. While the core matter of a general context – in our example the shape of the landscape - remains invariant, we must not forget that there is an infinite number of ways in which the “same” context could change dynamically.

If there are significant differences in a context then another pattern might provide a better solution. The form of a solution is only adequate and of value if it still fits the context. For example, the very same form is no longer a solution if an essential part of the context (such as our starting position) changes.

The solution only fits to a certain context.

If the context changes (for example we start at a different position or we are in a different environment) the solution changes.

The core problem that we cannot pass all areas remains but the specific forces change.

Fig. 2. Paths are solutions.

A change in context can make new paths possible as well (e.g. a bridge over a canyon) or eliminate paths that have worked in the past (e.g. a rock slide blocks the way). The context implies which solutions could work because it contains the forces and problems that need to be resolved by the solution.

4. UNDERSTANDING PROBLEM AND FORCES

The forces “must be rooted in the context and have arisen from here.” (Buschmann, Henney, and Schmidt, 2007). In a changed context the same solution form may not fit any longer. Another context sets new
constraints, boundaries, introduces new requirements and offers different opportunities. For example, the equipment and training of a hiker is part of the context and implies different fields of forces. An untrained hiker might be forced to choose a path that is not too steep. The right equipment might offer new opportunities (e.g. climb a steep wall) but also introduce new limits. Constraints, boundaries, requirements and opportunities are different types of forces.

Forces can support each other or conflict if they imply different approaches. Such conflicts are problems that need to be resolved. The problem and forces of a given context are usually discussed in separate sections because they are important to understand why a pattern is shaped the way it is.

If forces are the reason to build a solution in a specific way that works, we can consider forces as the cause that leads to the pattern. For example, what is the cause for the problem that we cannot go straight to our destination? Originally, it was the rock face that blocks our way. It forces us to take another way. That particular force is the original problem, the one that is problematic in the situation we are in. That force is in conflict with our desire (or “force”) to reach the target directly. If we are looking for a way that brings us to our destination we have to account for all the forces that influence our chosen path in the given context. There are some forces that cause the original problem and there are more forces that shape the path of the solution.

Fig. 3. The (−) arrows denote forces that deny us a specific path, e.g. we cannot cross over a canyon (1) or climb a steep wall (2). The positive forces (+), on the other hand, are attractive ways to go. There are also some attractive places to which positive forces point, such as a place to get fresh water (3), or the actual destination (4).

In order to capture the forces we need to analyze the relation between the solution and the context. A key is to ask why questions. Why do we have to follow this specific path? Why do we have to go there? Why do we need this specific form? Why can’t we do another thing instead? Each single force gives another answer to such why-questions. A force explains the cause for a specific design decision by giving the “because” to the “why”. In explaining the reasons for the solution form it helps us to understand the pattern rather than blindly following an advice. This understanding of a pattern is essential for judging whether it fits to the problem at hand and to adapt it to the specifics of the situation. A lot of knowledge is shared by discussing the forces since “experts know how to play with the various forces in their area of expertise”. (Schümmer & Lukosch, 2007)

5. UNDERSTANDING SOLUTIONS

A solution is one known way that takes into account all the forces that matter in a specific context and balances them to a satisfying extent. The form of the solution is a path that has proven in the past to actually lead to the intended goal and takes the forces appropriately into account. It does not mean that it is the only path that does exist nor does it claim to be the best path. There might be paths that even fit better to the context but that have not been found yet.
The term pattern suggests recurrent solution forms (Rising, 1998). And that is what happens if people use a path: no two hikes along a path will be identical. We will use detours, walk crisscross and unfold the hike every time in a new way while still following the same way. That refers to Alexander’s second element of the definition of patterns. It is a solution which occurs over and over … without ever doing it the same way twice.

![Figure 4. Variance of hikes.](image)

While there is variance, the general structure is preserved. Every concrete journey along a path has the same structural quality even if each instance unfolds differently. This structural symmetry lets us find abstracted representation of an actual path. However, the range of possible variation is different for the various parts of a path. At some points the space of a path may be broad, allowing many different steps to move along the same path. At other points, the path may be narrowed or obstacles only allow specific moves. Those points are critical and need more attention to make the path a success. It is therefore that we must find a medium level of abstraction. Like a map, a pattern description has to provide enough information to actually follow the solution path. It will leave out details and concentrate on hallmarks that help designers to find their way. But it must not be too abstract. Otherwise we are loosing the form and the specific structure that guides the designer through the territory. To illustrate this, consider the different options representing a path in figure 5.

![Figure 5. One could use a single instance that leads along the path by example (b). One could construct a simple model which is still a proper instance of the pattern (c). Note that it is not yet an abstraction, even if it might be based on average values. Based on the model, one could abstract to essential points or milestones (d). However, too abstract representations lose significant information (e).](image)

Each of the illustrations represents a structural relation of the real world. Geographic maps (as used in the examples) represent the spatial relations of a territory. Such maps help to illustrate how the conditions of the territory offer different paths and also set boundaries. A map can clarify the structure of the path and the environment. But it must not be confused with the real territory and the actual paths.

Instead of using formal maps, informal maps could tell the story in a different way. Classic geographic maps have a bird’s eye perspective. However, when you ask for directions you often get instructions where to go next (“turn right at the third intersection”). Such directions are sometimes supported by demotic maps that are scribbled and look like drawings on the back of a napkin. Such diagrams are easy to create and understand but still show the important relations between the elements. The point is that informal ways of
describing forms (such as paths or patterns) are very often quite precise because they take into account what actually matters in the given context. Sometimes a stone may be ignored, at other times the stone can mark a change of directions, and sometimes it is a spot of danger. Whether or not the stone is included in the map is not governed by formal rules but depends on its importance finding the right way.

6. UNDERSTANDING CONSEQUENCES

The context shown on the map allows more than one solution path. Each path has different advantages, disadvantages, liabilities, and suggests different next steps. For example, the path that leads to the historic site certainly has the advantage of visiting that place. However, it requires more time. The two paths compete with each other.

In the process of searching a decision between different solutions, the pros and cons are weighed against each other; the consequences are compared. “In practice it is rare for solutions to be ‘right’ or ‘wrong’. Instead, a proposed solution will typically do some things well and other things less well.” (Koenig, 1998)

The overall situation will determine the actual path taken. If the hiker has a special interest in historic sites this interest “forces” him to take the longer way because he “has” to see it. In this context the path that runs along the historic site is best for that hiker. However, in a slightly different context there might be a time constraint to reach the goal. In that case the hiker might be forced to take the shorter path because reaching the goal in time (e.g. before sunset) might be more important than seeing the historic site. The better we understand the consequences the better we can find an appropriate decision. If we know the advantages (values) and disadvantages (costs) of a path we can better decide which one fits the problem at hand.

Fig. 6. Alternative solution paths.

Fig. 7. Different consequences of a solution path.
Which consequences matter depends on the specific context or situation. Small changes in the context (time constraints, personal interests) have impact on the path we consider best. There are also situations in which two paths are equally valuable. For example, if one path leads to a historic site and the other to a scenic view, and both are equally interesting for the hiker then the decisions might depend on mood or previous experience (if the hiker has seen already five historic sites he might choose a scenic view). Both are contextual properties as well. Unless one flips a coin each decision is based on the fact that one path is favoured over the other.

Once we have made our decision for one path we have to live with the resulting context and its liabilities. For example, we may encounter further obstacles on our way. The path may lead to our goal but we have to take care of some challenges. These challenges are local problems that occur in the context of the chosen solution. It is common to describe recurrent local problems and their solutions as separate patterns that can be used in the context of the current pattern. That is one reason why solutions frequently refer to other patterns.

The choice of a path also has consequences for the next steps. Once it is decided where to go there is a resulting context that suggests which sub-paths can be followed and which preceding and succeeding paths are available. The start and end point of a path have to connect to surrounding paths. At any time, the steps that can be followed next depend on previous decisions.

7. UNDERSTANDING PATTERN LANGUAGES

“And all these rules of thumb – or patterns – are part of larger systems which are languages” (Alexander, 1979, p. 202).

So far we have learned that no pattern should be considered in isolation. In each of the previous section the context played an important role. Moreover, we have seen that once a pattern has been chosen the resulting context suggests new patterns to generate the solution. This interconnection of patterns is captured in pattern languages. A pattern language consists of both patterns (the vocabulary) and rules how patterns can be used in conjunction (the grammar). Noble (1998) distinguishes between the primary relationships that “a pattern uses another pattern, a pattern refines another pattern, or a pattern conflicts with another pattern”.

Let us first understand why patterns build a vocabulary. Each pattern description always starts with a name that denotes the pattern. Likewise, people usually give names to paths in order to refer to them. More generally in our natural language words are used to denote categories (Löbner, 2002). For example, when we use the term “tree” we refer to a specific structure. It helps our communication to say “tree” rather than describing that structure. Thus, a pattern name implies a specific structure that can be expressed by the use of the name. Of course we can express more things if we have a wider vocabulary. Before we can follow a (proven) path we have to know that it exists. The more paths we know of, the more flexible we are to choose our routes. The more solutions we know, the easier we can generate more complex designs because we are able to express the designs in terms of those known solutions – the named patterns.
Larger solutions build on smaller solutions. Alexander writes: “Each pattern then, depends both on the smaller patterns it contains, and on the larger patterns within which it is contained.” (Alexander, 1979, p. 312).

If we have a pattern language with a rich vocabulary we can make the relations between patterns explicit. Elements of the context and elements of the solution can be referred to by using pattern names rather than explicitly describing the structure. References to other patterns are highlighted in pattern descriptions by using Capitalized Letters. By those references, and sometimes in separate sections labelled “Related patterns”, a grammar for the appropriate use and combination of patterns is partly defined.

For example, once we have chosen a specific path to cross a mountain, we can denote that PATH LONG MOUNTAIN PATH. The name is already expressing some of its properties: it is long and involves a mountain. We can now refer to it in other paths that lead to it or follow up from there. In the description of the Long Mountain Path we could also refer to connected paths. Thus, we are providing further context for it and it becomes more whole since we get to know how to get there and how to progress.

Instead of describing the LONG MOUNTAIN PATH step by step we could refer to sub-paths between intersections. This provides further flexibility because there may be alternative sub-paths between two intersections. Say we have seven intersections on our path and each intersection is connected by two different sub-paths. Then we can, by reference to the sub-paths, compose $2 \times 2 \times 2 \times 2 \times 2 = 26 = 64$ different paths over the mountain. Instead of describing each of these paths (as different mountain paths) we only need to describe the twelve sub-paths and a more general (and abstract) LONG MOUNTAIN PATH that refers to the sub-paths.

Of course we could further divide the sub-paths into smaller ones that take more alternatives into account. And the mountain path itself could be considered as just one option to cross the mountain, being a subdivision of a path on a larger scale.

As part of a language those patterns (or paths) can be used to generate infinite new instances by both combination and adaptation. THE LONG MOUNTAIN PATH is one example for a pattern. The name is chosen in a way that it can be used in our natural language where we can express combinations with other paths. It becomes a part of our language.

We could also introduce a more detailed pattern language that can be used to generate the LONG MOUNTAIN PATH. This pattern language would consist of the sub-paths as elements of the language and we could use them to express the LONG MOUNTAIN PATH.

8. CONCLUSIONS

The path metaphor illustrates some important concepts of patterns such as mapping the structural relations of elements. In software design, UML class diagrams are mappings of object relations and interactions.

The structure of a path is a metaphor in respect to software design patterns or pedagogical patterns due to its analogies. These analogies can be found because a path is more than a metaphor in respect to the pattern concept. It is an example of a pattern because each path solves a problem of getting safely from one point to another. Hence, paths are a special category of patterns. In our everyday language we speak of ways to achieve something or step-by-step solutions. The original meaning of method is “a way to a specific goal”. If a path is an example for a pattern then all properties of patterns should apply for paths as well. Hence, we can use the visual nature and common familiarity with paths to explain the properties to beginners and sceptics.

However, there are limitations of the path example that do not show the complexity and flexibility that is found in other patterns. For example, a path only has to fit to its local environment and to the previous and succeeding step. But there are patterns whose elements have to fit to a larger number of other parts at the same time.
Another special property of physical paths is that a person can only choose one path at a time. Large design projects on the other hand usually require that users follow multiple (metaphorical) paths at the same time. In software architectures, the same class can play a role in multiple patterns at the same time. This raises the question of which types of patterns can be combined with each other to another level. The pattern of a path can be combined with other patterns such as WATER BOTTLE or RAIN JACKET simultaneously. But the combination with other physical paths can only take place in a sequence.

I have focussed on explaining context, problem, forces, consequences, and solutions using the path example. Yet most pattern formats I know use more description sections since we can elaborate each of these views in more detail. For example, very often the “intent” is explicitly stated in a description field. The intent is part of the context or situation. The forces, too, can be described in several sub sections. Some patterns have a “rationale” section that explicitly reports how the forces have been resolved by the solution. The solution itself is tackled from multiple perspectives, including “summaries”, “diagrams”, “discussions”, “examples” or “stories”. The “consequences” are often sub-divided into “advantages”, “disadvantages”, “liabilities”, “resulting context” etc. Some of the typical description fields for software design patterns are discussed in A Pattern Language for Pattern Writing (Meszaros, and Doble, 1997). Which format is chosen depends on both the preferences of the authors and the domain of the pattern. If a hiking path is described it might be a good idea to include seasonal conditions as a section in the context statement. Educational patterns sometimes state the group size or duration of a method explicitly. There is not one golden pattern format. However, the context, problem, forces, the solution and its consequences should be captured in each pattern. Also, patterns should always have an expressive name to make it part of the vocabulary of a designer.

9. FUTURE WORK

While the map and the path examples have helped to visualize the concept of patterns, the graphics could still be improved. I am currently working on representations that make the statements provided in this paper clearer by using a simplified mapping.

In creating the illustrations and using the path as an example I got a better understanding of patterns and pattern languages. The next questions that should be explained using the path example are: what makes a pattern a good pattern? Which are the qualities of a pattern that we are looking for? Certainly we want that the pattern works and solves the problem to a satisfying degree. But a pattern should also be elegant, work with other patterns to form a solution on a larger scale, and be flexible to be used in various situations. In a follow-up paper I shall discuss qualities of patterns such as encapsulation, abstraction, openness, variability, generativity, composability and equilibrium (Lea, 1994) as well as wholeness, the quality without a name, reason and evidence, fitness and meaning. All these qualities will be illustrated using the path metaphor.
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