EVOLVING DESIGN LAYOUT CASES TO SATISFY FENG SHUI CONSTRAINTS

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Abstract. We present a computational process model for design that combines the functionalities of case-based reasoning (CBR) and genetic algorithms (GA's). CBR provides a precedent-based framework in which prior design cases are retrieved and adapted in order to meet the requirements of a new design problem. GA's provide a general-purpose mechanism for randomly combining and modifying potential solutions to a new problem repeatedly until an adequate solution is found. In our model we use a GA to perform the case-adaptation subtask of CBR. In this manner, a gradual improvement in the overall quality of the proposed designs is obtained as more and more adaptations of the design cases originally retrieved from memory are evolved. We describe how these ideas can be used to perform layout design of residences such that the final designs satisfy the requirements imposed by *feng shui*, the Chinese art of placement.

1. Introduction

We have developed a process model of design that combines the precedent-centered reasoning capabilities of case-based reasoning (CBR) (see for example (Kolodner, 1993)) with the incremental evolution of multiple potential solutions, an idea taken from the paradigm of genetic algorithms (GA's) (see for example (Goldberg, 1989)). The process model involves the use of CBR as the overall reasoning strategy and the use of a GA to perform the case-adaptation subtask. Because a general-purpose knowledge-independent GA is used, case adaptation is knowledge-lean. It is only in the evaluation module of the GA that domain knowledge is required so that proper decisions are made about which potential solutions generated by the GA are useful to keep in future GA cycles.

Our process model is shown in Figure 1. In this model we assume the existence of a case memory in which descriptions of previously-existing designs are stored. The cases that are retrieved from memory given a new design specification are adapted by repeatedly combining and modifying their features. After each cycle of combination and modification, solutions are evaluated and the best are kept, to be adapted in the next cycle. Through this incremental, evolutionary process, eventually the case adaptation process converges to a satisfactory solution to the new problem. The solution will contain features and/or modifications of features from several of the cases that were initially retrieved from memory. Thus, our process model adapts past designs by evolving different combinations of their features in parallel and continuously, until a satisfactory combination is found.

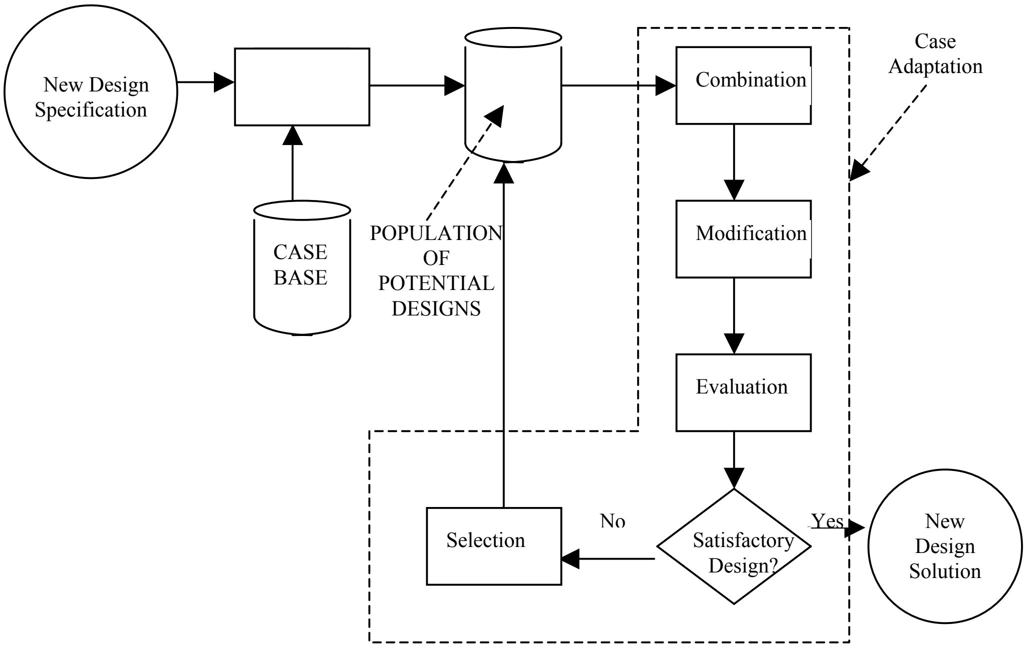


Figure 1. Process model.

The main emphasis of the process model is on proposing new designs based on the knowledge contained in previously-known designs, i.e., it is a precedent-based approach. But a major component is the evolutionary approach to adapting the known designs in order to generate solutions to new problems. The two strategies of CBR and GA's complement each other. The cases retrieved from memory serve as the initial population to a genetic algorithm, while the genetic algorithm adapts the cases until it finds an acceptable solution.

We have applied this process model to performing layout design of residences such that the final layouts proposed satisfy the constraints imposed by *feng shui*, also known as Chinese geomancy. The cases initially in memory do not necessarily have to conform to the principles of *feng shui*, but our process model, by combining different features from different cases (and intermediate potential solutions), can produce results that *are* acceptable according to *feng* *shui*. To apply our process model to the *feng shui* domain, knowledge about this domain has been included in the evaluation function of the case adaptation GA. Our process model has also been applied to the domain of structural engineering design of high-rise buildings (Gómez de Silva Garza and Maher, 1998).

2. Representing Layouts and *Feng Shui* Knowledge

Feng shui, also known as Chinese geomancy, is an ancient Chinese technique that, among other things, determines the quality of proposed or existing layouts of residences according to several rules of thumb. Some of these heuristics seem to have a basis in common sense, or in a psychological or sociological appreciation of the human beings that inhabit (or intend to inhabit) the residence. Other heuristics seem to be of a more superstitious nature.

There are several different *feng shui* sects that may contradict each other or place different priorities on different aspects of residential layouts. Despite this variety, of prime importance to performing any *feng shui* analysis is information on the relative positions of objects. In addition, other attributes of objects are usually also taken into account, such as their orientations, shapes, and relative sizes. In our work we have used the knowledge of *feng shui* presented in (Rossbach, 1987), which corresponds to the Tibetan black-hat sect of *feng shui*.

Feng shui analyses different aspects of a residential layout to determine its auspiciousness or lack thereof. Some classes of inauspicious layouts can be "cured" by the proper placement of an acceptable curing object. Thus, *feng shui* knowledge is complex, in that some potentially bad layouts can actually be acceptable if the proper cure is present. It is not just a matter of determining whether a layout is "good" or "bad," but even if it would normally be considered bad, one has to determine whether it has been cured or not before rejecting it outright.

The *feng shui* knowledge contained in (Rossbach, 1987) applies to three different levels of description of a residence:

- The landscape level (the location of a residence with respect to other objects in its environment such as mountains, rivers, roads, etc.),
- The house level (the relative placement of the rooms and functional spaces within a residence, such as bedrooms and bathrooms, as well as the connections between them, such as doors and windows), and
- The room level (the location of furniture, decorations, and other objects within each room or functional space in a residence).

Our knowledge representation scheme thus keeps this separation into three possible levels of description for each residence.

Feng shui analysis assumes knowledge of spatial relationships among the objects at the different levels. Absolute locations and exact measures of distances and other geometric quantities are not as important. Because of this, a qualitative spatial representation has been chosen to describe the locations of objects within each of the three levels. We locate objects on each level in a 3x3 spatial grid, with each sector within the grid assigned a unique number between 1 and 9 to identify it. The grid is shown as follows, with north assumed to be at the top of the page:

1	2	3
4	5	6
7	8	9

Objects can occupy more than one grid sector, and grid sectors can contain more than one object, making the representation flexible. The resolution of this representation is not high, but considering the qualitative nature of a typical *feng shui* analysis and the number of objects that typically need to be represented at each of the three levels, it is adequate in most cases.

2.1. CASE AND PHENOTYPE REPRESENTATION

Each design case is a residence described at the landscape, house, and room levels. Within each level, objects are described by attribute-value pairs that are relevant to *feng shui* analysis. Some attributes such as locations and types of objects are required for all objects, whereas others such as shapes and steepness are optional, and don't even make sense for some objects. A diagrammatic example of a residence is shown in Figure 2. This is followed by an abbreviated version of the symbolic case representation of the same residence.

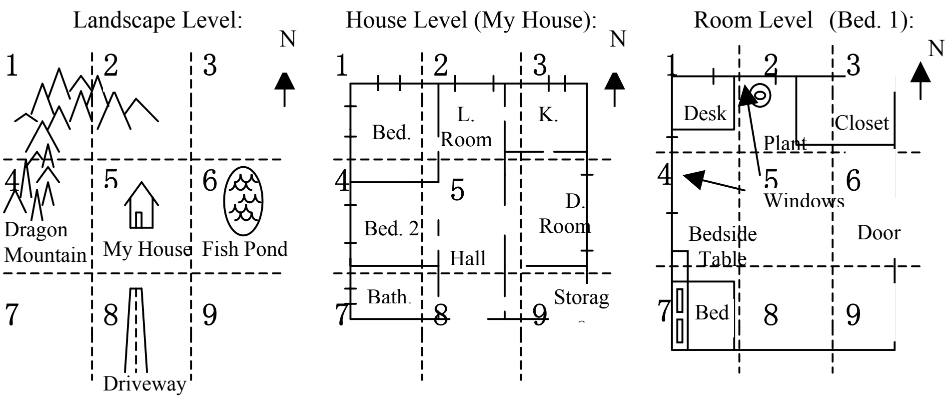


Figure 2. Three levels of description of a residence.

```
(((level landscape)
  (elements (((type hill) (name dragon-mountain)
             (location (1 2 4)) (steepness high) ...)
            ((type pond) (name fish-pond) (location (6))
             (clarity murky) ...)
            ((type house) (name my-house) (location (5)))
            ...)))
 ((level house)
  (elements (((type bedroom) (name bedroom-1) (location (1))
             (shape square))
            ((type bedroom) (name bedroom-2) (location (4)))
            ((type hallway) (name hall-1) (location (5 8)))
            ...))
  (connectors (((type door) (name b2-hall) (location (5))
               (side-a bedroom-2) (side-b hall-1)
               (direction ew))
              ((type window) (name b1-window-1) (location (1))
               (side-a bedroom-1) (side-b outside)
               (direction ew))
              ((type window) (name b1-window-2) (location (1))
               (side-a bedroom-1) (side-b outside)
               (direction ns))
              ...)))
 ((level room)
  (name bed-1)
  (elements (((type bed) (name b-1) (location (7)))
            ((type desk) (name d-1) (location (1)))
            ((type window) (name w-1) (location (1 2)))
            ...))))
```

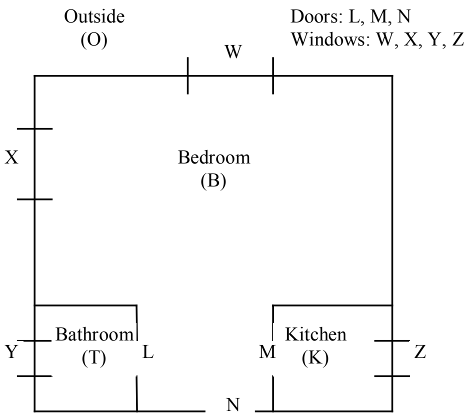
Retrieved cases are used in our process model to seed the population of our case adaptation GA, i.e., as the initial “proposed solutions” in the GA’s population. Therefore, the representation of a phenotype (the physical manifestation of the potential solutions being generated and evolved) in the GA is the same as the case representation described and shown above.

2.2. REPRESENTATION OF DESIGN GENOTYPES

The GA assumes a dual representation of potential solutions: the genotype representation is the basis for the genetic operators of crossover and mutation, and the phenotype representation is the basis for evaluation of fitness. Given our representation of feng shui analysis, we use the same object representation for both the phenotype and genotype at the landscape and room levels. At these levels, the objects are located on the grid and their spatial relationships can be derived from the location attribute. The objects in the house level require a more explicit representation of spatial relationships and adjacencies. For this reason, the genotype representation of the house layout is based on an adjacency matrix.

Figure 3 shows a simple residence (for example, a studio apartment) at the house level and its associated genotype. The rows and columns of the matrix represent the rooms and functional spaces in the floor plan, with an extra one to represent the outside (O). The matrix item a_{ij} is the empty list if rooms/spaces i and j are not adjacent. Otherwise, a_{ij} lists which connectors cause i and j to be adjacent.

Floor Plan:



Genotype:

	B	T	K	O
B	()	(L)	(M)	(N,W,X)
T	(L)	()	()	(Y)
K	(M)	()	()	(Z)
O	(N,W,X)	(Y)	(Z)	()

Figure 3. A residence and its genotype.

2.3. REPRESENTATION OF *FENG SHUI* ANALYSIS KNOWLEDGE

Feng shui analysis knowledge is used in the evaluation function of the GA. We have taken the text description of the analysis knowledge and converted it to a set of constraints; each constraint is implemented as a procedure. There are several constraints at each level of description of a phenotype.

An example of a *feng shui* constraint at the house level, quoted directly from (Rossbach, 1987), is:

> Traditionally, the Chinese avoid three or more doors or windows in a row...this...funnels ch'i [positive energy] too quickly...[CURE:]...to stop ch'i from flowing too quickly, hang a wind chime or crystal ball...

This constraint is implemented by first finding the description of all the connectors at the house level, particularly their locations and directions. If at least three connectors are aligned such that their locations are in consecutive (or the same) sectors *and* they are all have the same direction (e.g., north-south), then the constraint has been violated. However, before jumping to this conclusion, we must check whether or not there are any crystal balls or wind chimes in the house that are positioned in line with the violating doors/windows.

The pseudocode that performs this analysis, i.e., the procedural representation of the constraint, given a phenotype P, is shown as follows:

```
Get the list C of all connectors in P;
Get the list Q of all potential cures for this constr. in P;
For each connector c in C or until a bad omen has been found:
   Get the location l of c;
   Get the direction d of c;
   Set the list of connectors LU lined up with c to the empty
      list;
   Get the list Reduced of all elements in C except c;
   For each connector r in Reduced:
      If the direction of r is d And
         the location of r lines up with l along direction d,
         Then add r to LU;
      End-If;
   End-For;
   If there are two or more connectors in LU And
      no potential cure in lines up with r,
      Then signal a bad omen situation;
   End-If;
End-For;
```

At the house level, additional constraints have been implemented that are not imposed directly by the *feng shui* domain, but rather by common sense. For instance, after the GA operates on its population some of the proposed solutions might have "pathological" features such as a house ending up with no door connecting it to the outside. These non-viable designs are also detected, as are those that violate the principles of *feng shui*, by the GA's evaluation function.

3. Implementation of the Process Model

The process model presented in this paper has been implemented in a system called GENCAD. For the *feng shui* application, the GA operators are applied to one of the three levels of description of a residence at a time. This is because there are very few *feng shui* constraints that relate objects belonging to different levels of description; the constraints involve relations between objects within the same level. Thus, potential solutions to the new problem at the landscape level can be evolved (and evaluated) independently from potential solutions to the same new problem at the house level, etc.

3.1. CROSSOVER

Crossover is an operator that combines features of two potential solutions by "cutting" the descriptions of the two solutions and "pasting" together pieces from the two old solutions to create two new potential solutions. At the landscape and room levels of description of a residence, crossover simply consists of randomly choosing a crossover point in the descriptions of the two parent landscapes (or rooms), performing the "cut" operation at that point, and performing the "paste" operation of the resulting pieces such that each resulting offspring combines features of each of the parents.

At the house level, crossover is a matrix operation, since the genotype is an adjacency matrix. Figure 4 shows a schematic of this matrix-based crossover operation (where the vectors that label the adjacency matrices with the names of rooms are also crossed over). The parent genotypes are of different sizes because they have different numbers of rooms.

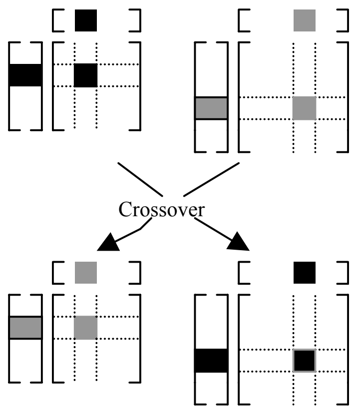


Figure 4. Matrix-based crossover.

The matrix-based operation that implements crossover at the house level is based on extracting (and interchanging) submatrices from each of the parent genotypes, resulting in offspring genotypes that combine both elements (e.g., bedrooms, kitchens, etc.) and connectors (e.g., doors, windows, etc.) of both parent genotypes, and at the same time are internally consistent (i.e., meaningful semantics can be ascribed to them). After the operation, the equivalent offspring phenotypes together contain the same types of elements and connectors that the parent phenotypes had. Each of the offspring has the same total number of elements as its parent, though each will have some elements inherited from both parents. The total number of connectors in each offspring might be different from that of its parent, but the total number of connectors in both offspring will be the same as the total in both parents together.

3.2. MUTATION

The mutation operator makes modifications to the genotype. The modifications performed by mutation are random, so the "right" type of mutation (in order to achieve convergence, or to achieve it faster) might not occur quickly, and many useless mutations might have to be explored before a "good" one occurs. The mutation operator can be very useful in achieving convergence in situations where crossover would not search enough parts of the solution space.

Mutation is implemented by randomly choosing an attribute whose value will be modified, and then randomly choosing a new value for it, from amongst a list of values known to be valid (meaningful) for the given attribute. The system's memory contains knowledge of which values are acceptable for each known attribute in the *feng shui* domain.

3.3. EVALUATION AND SELECTION

The evaluation function of the GA embodies the *feng shui* knowledge. This knowledge is implemented procedurally, looking for potential "bad omen situations" (i.e., constraint violations), and if found, looking for the existence of potential "cures" for these. The total fitness F of a given phenotype, given N constraints (C_1 through C_N) and M problem requirements (R_1 through R_M), is calculated with the following equation:

$$F = \sum_{i=1}^{N} C_i + \sum_{j=1}^{M} R_j$$

where $C_i = 0$ if constraint C_i is not violated by the phenotype or
$C_i = 1$ if constraint C_i is violated by the phenotype, and
$R_j = 0$ if requirement R_j is met by the phenotype or
$R_j = 1$ if requirement R_j is not met by the phenotype.

At the end of each GA cycle, the total fitness of each newly-generated proposed design in the population is calculated. Convergence to an acceptable solution occurs if an individual in the population has a total fitness of 0, meaning that none of the constraints has been violated and all of the problem requirements have been met.

The best solutions (those with lower fitness value) found by combining the new ones with the ones from the previous GA generation are kept to participate in the GA's next generation, assuming that convergence has not been achieved. This process is known as selection. The percentage of solutions from the population that are selected is chosen so as to keep the total size of the population constant. This percentage depends on how many new solutions were generated in the previous generation (usually this will be a constant amount, but because of potentially meaningless solutions that are filtered out during crossover and/or mutation, it may vary).

4. Summary and Current State of the Implementation

We have presented a process model for design that combines the use of precedents, an idea taken from case-based reasoning research, with the incremental evolution of potential solutions, an idea stemming from genetic algorithms. This process model adapts design cases by evolving combinations and modifications of them until they achieve the user's problem requirements and they meet the constraints of the domain to which the process model is being applied. In this paper we have described the process model as it would be applied to the domain of layout design of residences that conform to the principles of *feng shui*.

Most of the process model and associated *feng shui* knowledge has been implemented. We are constructing a case memory of designs that we can use to test the process model on a domain where the constraints are defined independently from the precedents. We have presented results on the application of the same process model to the domain of structural engineering design of tall buildings in (Gómez de Silva Garza and Maher, 1998).

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