GENCAD: A Hybrid Analogical/Evolutionary Model of Creative Design

by

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• Problems are solved using information derived from precedents—the main idea behind analogy/case-based reasoning.

• Retrieved solutions to past problems serve as starting points for generating multiple random combinations and mutations (adaptations) of them, evolving them incrementally until a satisfactory solution to a new design problem is found—the main idea behind evolutionary algorithms.

• Resulting hybrid, integrated, process model can be recognised by case-based reasoning specialists as CBR, and can be recognised by evolutionary algorithm specialists as an EA—not just using some ideas from one area in the other.
**Analogical/Case-Based Reasoning:**
- Time-consuming and often problematic knowledge acquisition.
- Resulting knowledge quickly guides a system towards finding a solution to new problems.
- Case adaptation usually based on domain-specific heuristics resulting from knowledge acquisition.
- Does not rely on making random choices and hoping for the best.
- Has been used successfully in design tasks.

**Evolutionary Algorithms:**
- Does not require much knowledge acquisition.
- Begins proposing potential solutions at random.
- Convergence to a solution might require exploring large portions of search space.
- Does not need a priori knowledge to guide search.
- Has been used successfully in design tasks.

**GENCAD:**
- Requires some knowledge (cases and evaluation knowledge)—speeds up evolution.
- Does not need knowledge or heuristics for generating case adaptations—avoids bottleneck in development.
- Evolutionary algorithm generates adaptations quickly, randomly, and in parallel—flexible search for solutions.
- If convergence does not occur, can start again and perhaps succeed on 2nd attempt due to randomness guiding search in a different direction 2nd time around—robust.
Implementations of GENCAD:

- Application domain 1: structural engineering design of tall buildings.
- 60+ cases taken from textbook on subject provide case memory.
- Expert knowledge, tables of valid value combinations for different design parameters, textbooks, provide fitness function for evaluating quality of solutions proposed by EA.

- Application domain 2: spatial layout design of residences.
- Frank Lloyd Wright Prairie Houses provide cases.
- Tibetan Black Hat Sect of Feng Shui provides fitness function for evaluating quality of solutions proposed by EA.
Evaluating GENCAD According to Product:

Sample problem specification in application domain 2:

(((bedroom 3) (bathroom 2) (fireplace 1) (music-room 1))

Solution found:

- Solution combines stylistic features from several of the Frank Lloyd Wright cases in memory.
- Creative solution (due to separateness of bedrooms) if house intended for several unrelated individuals as opposed to a family.
Evaluating According to Process, Framework 1:

- Framework 1: zone of creativity potential within an exploration-transformation graph (Maher et. al, 1995).
- Degree of exploration and transformation of a process model assigned one of three qualitative values: mundane, novel, and original.
  - Mundane exploration ➔ quick convergence.
  - Novel exploration ➔ divergence and convergence.
  - Original exploration ➔ mostly divergent.
- Mundane transformation ➔ results from tweaking designs in solution space.
- Novel transformation ➔ results from modifying the range of values allowed for the variables that describe designs in the space.
- Original transformation ➔ results in altering the variables used to describe designs in the space.
- Zone of creativity potential: diagonal area of exploration-transformation graph in which neither is mundane (would be too boring) and both are not original (would be too crazy).
Evaluating GENCAD According to Framework 1:

- Type of exploration in GENCAD: convergent, and therefore classified as mundane (little abstraction or generalisation, but there is refinement through adding details from more and more cases).
- Type of transformation in GENCAD: original (can perform both parametric and structural adaptations through mutation and combination, resulting in new designs that can be quite similar or quite different from the ones originally in the solution space).
- GENCAD’s place in exploration-transformation graph thus lies within zone of creativity potential:

![Graph showing the exploration-transformation space with GENCAD's location marked as X in the zone of creativity potential.]

Key:
- Transition zones
- Zone of creativity potential
- X = Qualitatively assigned location of GENCAD in graph
Evaluating According to Process, Framework 2:

- Framework 2: creativity in computational models as a result of combining random decision-making and knowledge (Gómez de Silva Garza and Maher, 1998).
- Process models that only use a lot of deep (domain- and task-specific) knowledge cannot be considered creative: their outcomes when solving specific problems can be predicted a priori.
- Process models that only use a lot of randomness to generate solutions cannot be considered creative: their outcomes will, most of the time, be meaningless.
- For a process model to have the potential for creativity, it must involve making some random decisions, but it must also involve the use of deep knowledge to guide it along its search for solutions.
- Both features must be integrated in an “intelligent” way so that they complement each other:

<table>
<thead>
<tr>
<th>TOTALLY DETERMINISTIC:</th>
<th>TOTALLY NON-DETERMINISTIC:</th>
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<tbody>
<tr>
<td>• Intelligent problem solving.</td>
<td>• Dumb/blind problem solving.</td>
</tr>
<tr>
<td>• Non-creative (too predictable to produce unexpected results).</td>
<td>• Non-creative (too unlikely to produce valuable results).</td>
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Evaluating GENCAD According to Framework 2:

- In GENCAD knowledge in the form of cases and domain constraints used for evaluation of proposed solutions bias and guide the search for a satisfactory solution.
- In GENCAD random decisions in the crossover and mutation operators of the evolutionary case adaptation module mean that the potential solutions it generates cannot be predicted in advance.
- Since GENCAD combines both deep knowledge and random decision making in an “intelligent” manner, the process models has the necessary characteristics to produce creative designs.
Summary and Discussion:

- From the point of view of case-based reasoning, case adaptation in GENCAD is performed using an evolutionary algorithm.
- This case adaptation module needs knowledge in order to recognise good solutions, but does not need knowledge on how to generate potential adaptations.
- This simplifies the implementation of the case adaptation task compared to “traditional” case-based reasoning systems.
- From the point of view of evolutionary algorithms, the cases retrieved by GENCAD given a new problem serve as an initial population of potential solutions for the evolutionary algorithm to operate on.
- This gives the algorithm an initial bias/help/guidance that “traditional” evolutionary algorithms don’t have access to.
- The hybrid process model integrates the two approaches in a beneficial manner.
- We have evaluated GENCAD’s potential for creativity using a systematic methodology involving the analysis of several aspects of the process model.
- All criteria used for evaluation have allowed us to conclude that GENCAD is indeed a process model with a high potential for creativity.