WPI

Artificial Intelligence Views of Conceptual Design

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What is AI?

Herbert Simon:

> We call programs intelligent if they exhibit behaviors that would be regarded intelligent if they were exhibited by human beings.

Elaine Rich:

> AI is the study of techniques for solving exponentially hard problems in polynomial time by exploiting knowledge about the problem domain.

- Form theories about intelligent, rational reasoning.
- *Build systems to confirm theories.*
- Develop techniques.
- Build applications with techniques.

What is Designing?

- Designing is the generation of a Design description (or descriptions) by an agent (or agents) under the influence of certain constraints, preferences and evaluation knowledge.

- Influences derive from various sources, such as:
  - knowledge, skill and experience of agent doing the designing,
  - available tools and methods,
  - external imposition (such as needs, requirements, and the current state of the world),
  - physical limitations (such as scientific laws or physical properties)
  - guidance and support from a wide variety of knowledge and data.

Design Reasoning

- Abstraction
- Analysis
- Basic Synthesis (e.g., calculation)
- Classification
- Conflict Resolution
- Criticism/Suggestion
- Decomposition/Recomposition
- Estimation
- Evaluation
- Interpretation
- Modification/Adaptation/Patching
- Planning
- Prediction
- Presentation
- Retraction
- Reuse
- Simplification
- Selection

No Single Model

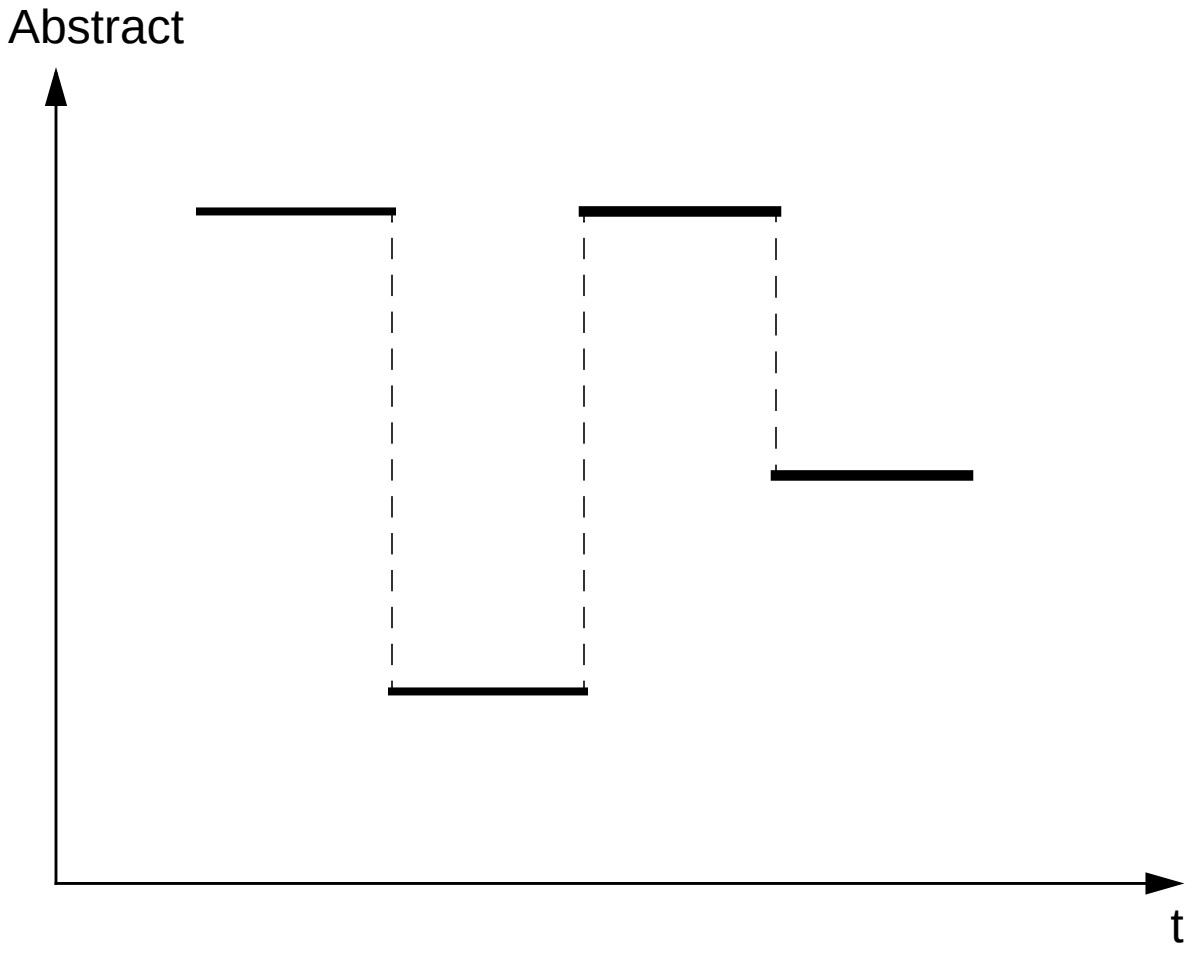
- There can be no **single** model of **all** design activity!

Variation:

- Designer's experiences
- Designer's domain knowledge
- Requirements
- Resources

Variation Example

Abstraction, Decomposition & Sequencing



- how abstract?
- how decomposed?
- what order?

AI in Design

Includes:

- modeling of designer activity.
- representation of designer knowledge.
- construction of systems that produce designs.
- construction of systems that assist designers.

Gain better insight into:

- nature of design processes and knowledge.
- methods for developing systems to support design activities.
- understanding of intelligent behavior.

What's Conceptual Design?

- Conceptual design takes the statement of the design problem and generates broad solutions.
- Solutions are in terms of functions and subfunctions, and schemes for implementing them.
- Schemes are in terms of configurations of types of components.

What's not?

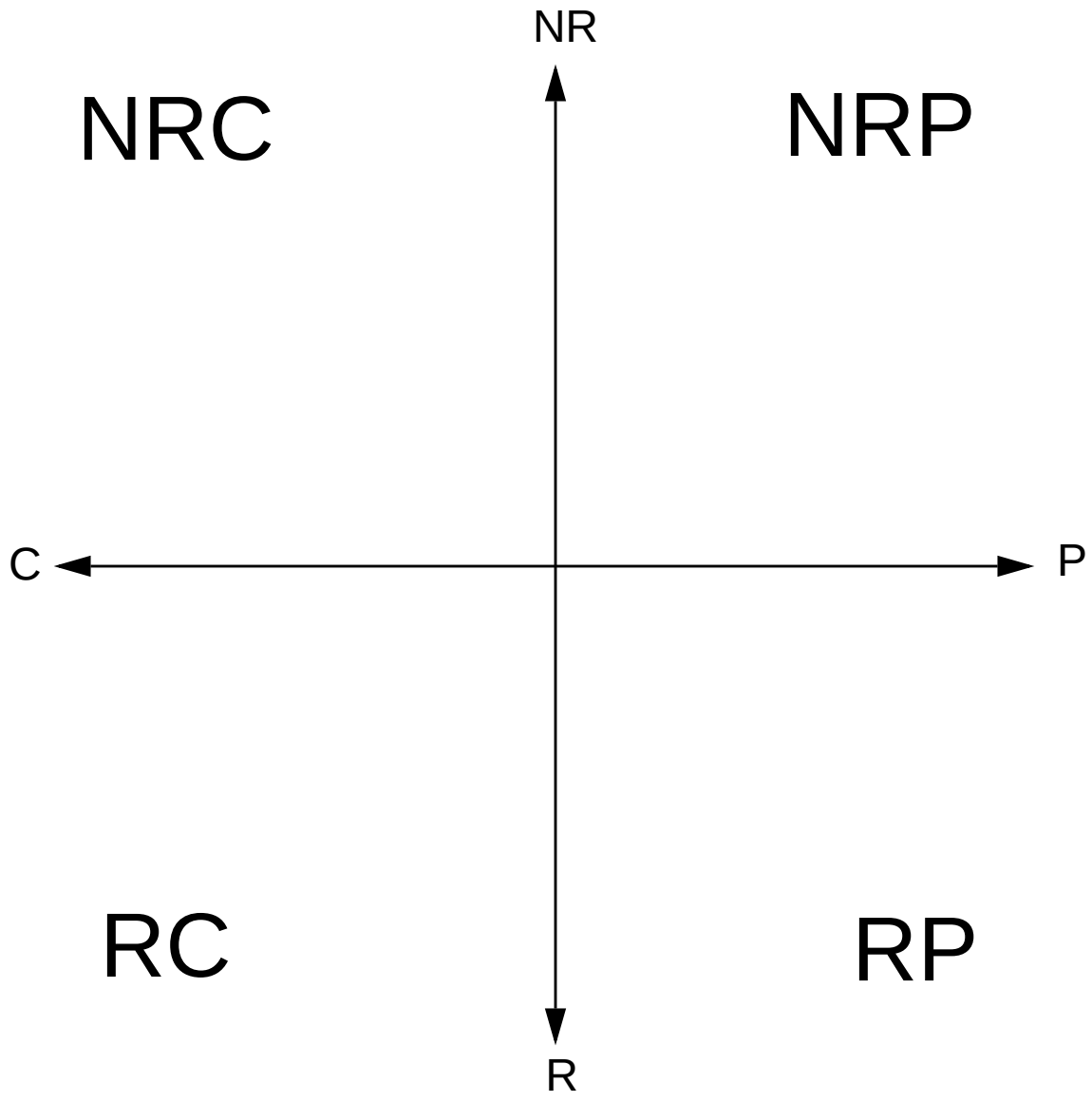
- Depends on amount of detail included.

- Not well distinguished by reasoning used.

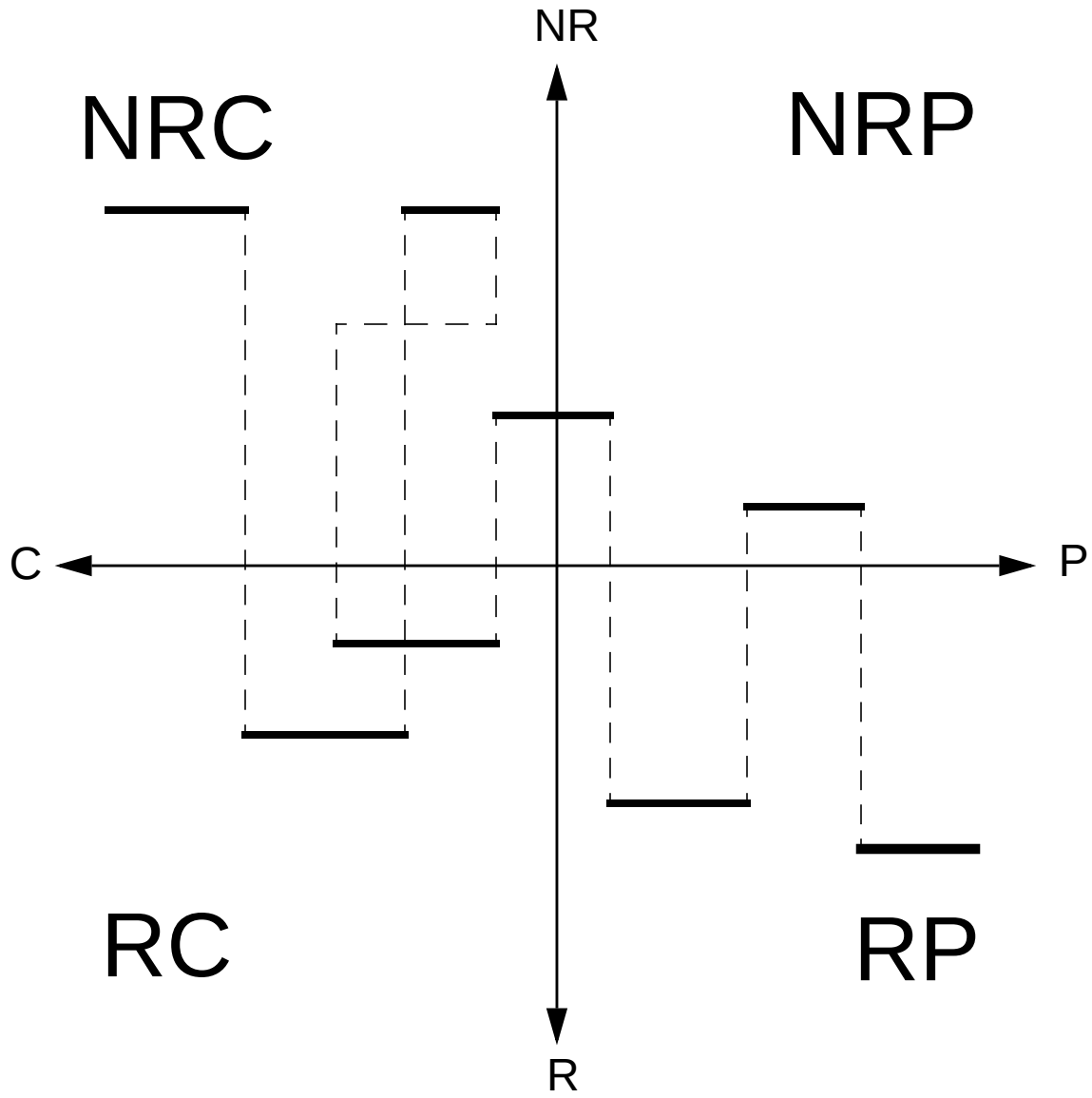
Includes, at least:

- Functional reasoning
- Decomposition
- Selection
- Configuration
- Evaluation

Dimensions



Path



Creativity

- Normally seen as starting at NRC.

- Creativity is relative to a standard, to expectations.
- The performance standard can be an Individual (or group) or a Population.
- Creative designing (Activity)
  vs. Creative designs (Result)

	Individual	Population
Activity	**A wrt I**	**A wrt P**
Result	**R wrt I**	**R wrt P**

Activity or Result vs. I or P

A wrt I:

designer's strategy is new or unusual relative to their own, normal activity for problems of this kind.

A wrt P:

designer's activity is judged relative to the population's normal activity.

R wrt I:

resulting design is new or unusual for the designer.

- Routine knowledge *could* produce this.
- This might occur from previously unused combination of techniques.

R wrt P:

resulting design is new or unusual with respect to the population's designs.

Conceptual D. Techniques

Analogy:

find a similar problem, and use its approach or solution, modified to fit this situation.

Case-Based Reasoning:

reuse an existing approach or solution (i.e., a “case”), perhaps with some adaptation.

Relax Constraints:

temporarily allow infeasible solutions, in order to increase search space.

Encourage Association:

association leads to analogy and CBR.

Graphical & Physical:

sketching and model-building leads to:

- association.

Techniques (continued)

Systematic combination:

combine types of solutions to subproblems.

e.g., ways to store energy.

Decomposition:

decompose the problem, and consider alternative decompositions.

Classify existing solutions:

look for classes of solutions and characteristics of problems to which they apply.

Functional reasoning:

reasoning about function-function, function-behavior and function-structure mappings.

Mutation:

tweak it and see.

Uses for AI in Conceptual D.

- Support Conceptual Designer.
  - remember
    (e.g., Design Rationale)
  - suggest
    (e.g., decompositions)
  - estimate
    (e.g., cost)
  - evaluate
    (e.g., manufacturability)
  - critique
    (e.g., configuration)

- Do Conceptual Design.

WPI AIDG Research

- Can it be done?

  e.g., multi-agent design systems;
  learning during design;
  inference using Design Rationale;...

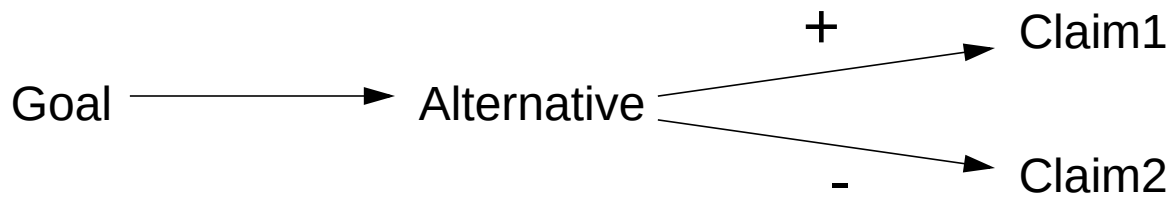
- What is the nature of...?

  e.g., Configuration

  Configuring = Selecting
  + Associating
  + Evaluating

Design Rationale (DR)

- Represents reasons behind each decision, including its justification, other alternatives considered, and argumentation leading to the decision.
- Aid for revising, maintaining, documenting, evaluating, and learning the design.



Reasoning using DR:

```
Best Alternative not chosen
   for Select Light Configuration
Selected Alternative:
   Mixed Light Types (Rating = 3)
Best Rated Alternative:
   All Lights Same (Rating = 5)
```

DSPL

- Design Specialists and Plans Language (DSPL) is a language in which to capture the knowledge of how to produce a design.
  - intended for routine design situations.
  - used on mechanical, electrical and civil engineering tasks.
  - requires parameterized situation.

DSPL Structure

<DSPL structure diagram here>

SiFAs

- Single Function Agents.
  - Small KB systems.
  - Experimental platform for investigating Concurrent Engineering systems.

F*unction:* "what to do"

e.g., select, critique, evaluate,...

P*oint of View:* "what to consider"

e.g., cost, strength

T*arget:* "what to work on"

e.g., material, process

- 'Select material from the pov of cost'
  F ***T*** ***P***

- SiFAs have conflicts and negotiate.

Decomposition

- Given structural, functional, case and heuristic knowledge sources, decompose a design problem.

- Select fragments of relevant knowledge that suggest decomposition.
- Combine to form decomposition hypothesis.
- Refine hypothesis with more evidence.

Discovering Methodologies

- Producing a design methodology for the design of engineered objects, where design process requires the use of knowledge from multiple disciplines.

- A methodology dictates how to order and coordinate design tasks.

Design Simplification

- Simplification by Analogy with stored simplifications.

- Designs are represented as Function + Behavior + Structure.

Expectation Formation

- Learning in a multi-agent design system.

- Acquisition of expectations:
  - predictive knowledge that helps agents to avoid regions of the design space with no solutions or ‘weak’ solutions.

- Learning proceeds by causal attribution and covariational analysis, using inductive learning.

Conclusion

- Very many opportunities:
  - for AI-based systems to assist with Conceptual Design.
  - for AI-based systems to do Conceptual Design.
  - for Conceptual Design to act as a catalyst for AI in Design research.
  - for AI to aid in understanding Conceptual Design.
- If you can’t build a software system to do it then you don’t understand it!
- Lots of small applications of AI will provide more than one big one!
- It’s an exciting area!