

Exploring Design Innovation: The AI Method and Some Results

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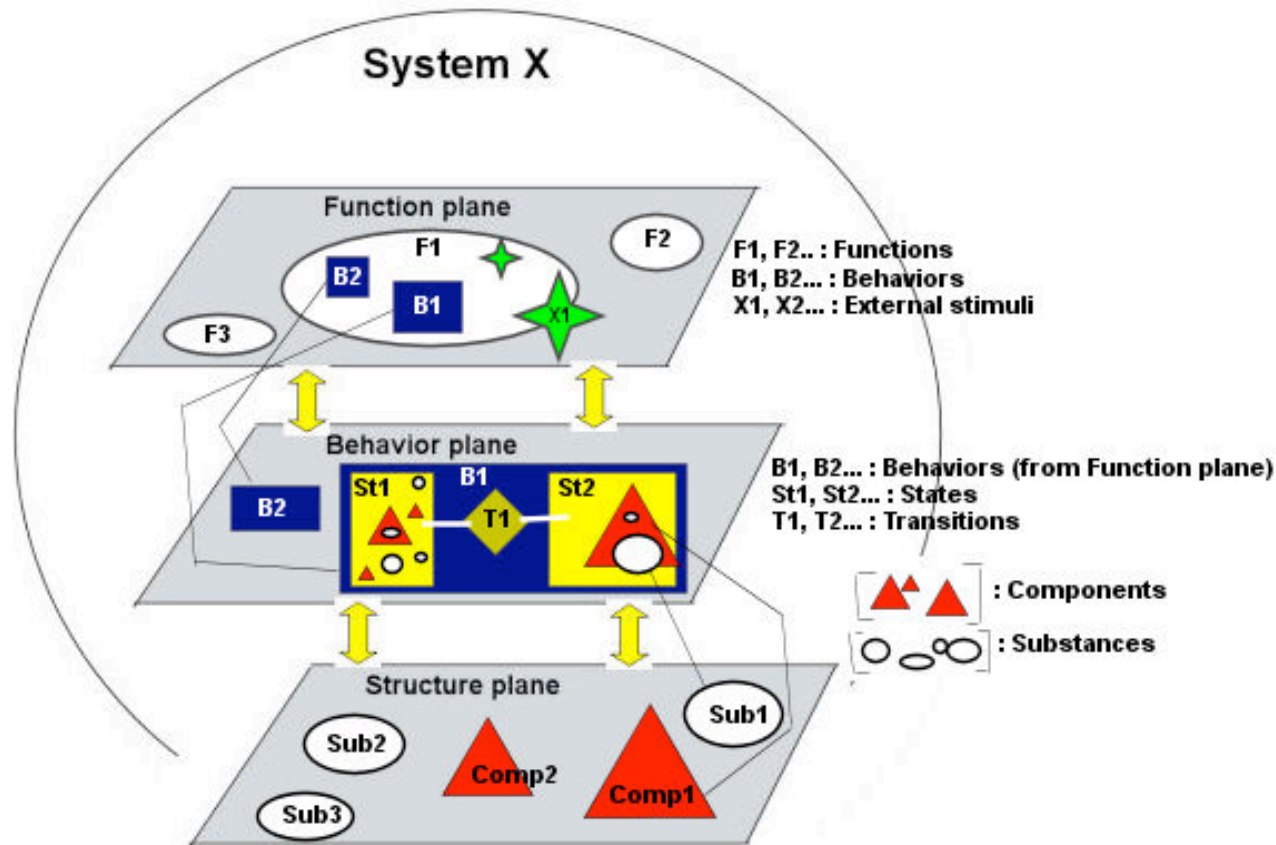
1. AI techniques provide both a process, and a content, account of reasoning.

Some cognitive theories provide only a process account. For example, the process of case-based reasoning: retrieval, adaptation, evaluation, & storage.

Writing an AI program also requires a content account of cases (and their indices).

The retrieval, adaptation and storage methods then are based on this account of case contents.

For example, the KRITIK theory of case-based conceptual design of physical systems [Goel and Chandrasekaran 1989, 1992] used Structure-Behavior-Function (SBF) models of designs as the case contents.



In KRITIK, the process of case-based conceptual design is grounded in the SBF schema and ontology, e.g., the SBF ontology directly provides the vocabulary for cases indices.

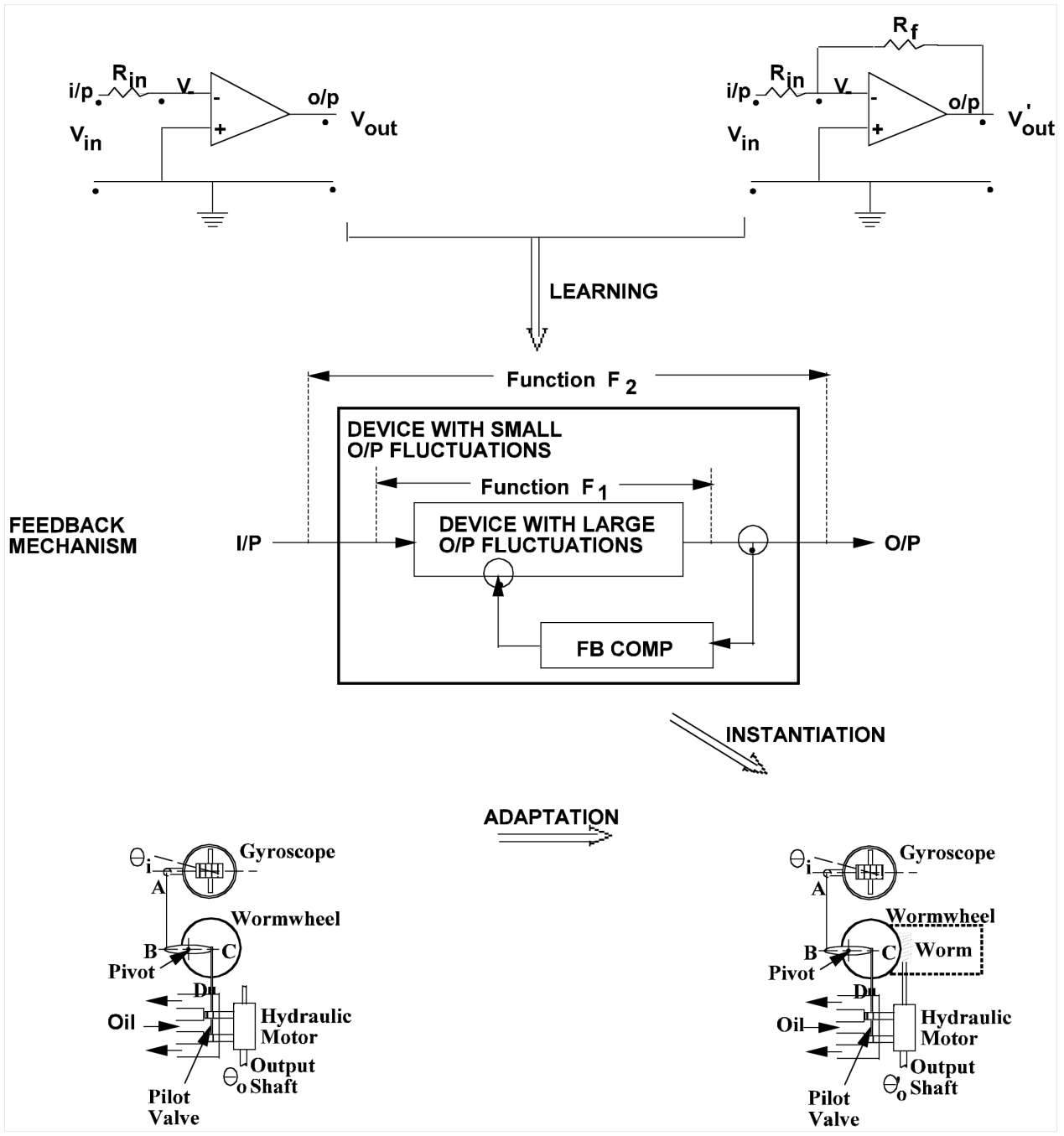
2. AI techniques provide an integrated account of reasoning, memory and learning.

A scientific theory of innovation and discovery should provide an account of memory and learning in addition to reasoning.

Some theories of creative design almost exclusively focus on design reasoning.

For example, design patterns in architecture design, software design, etc.

The IDEAL theory of analogy-based design innovation [Bhatta and Goel 1997, 1998] provides an account of the abstraction, reminding and transfer of design patterns in the design of physical systems.



3. AI techniques provide computational tools for aiding human designers.

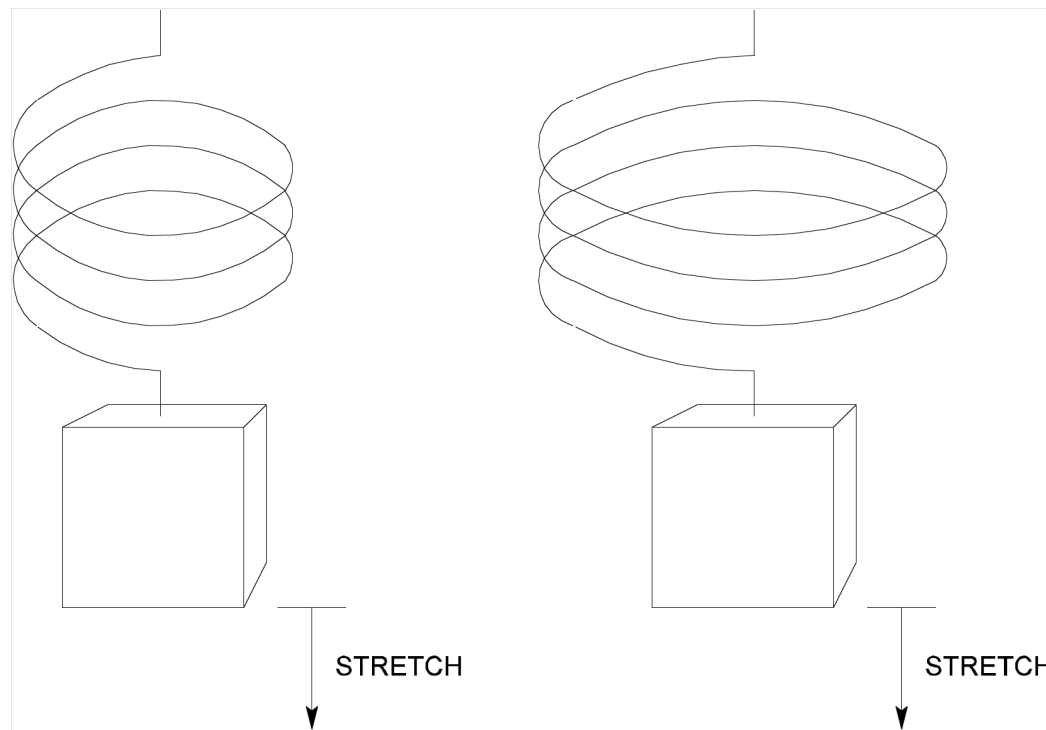
For example, case-based design aids provide access to libraries of design cases, leaving the tasks of adaptation, evaluation and storage to the human designer.

Case-based design aids typically are useful for domains in which good content accounts are not available, e.g., architecture design [Pearce, Goel, Kolodner et. al. 1992] and interface design [Barber, Goel, Simpson et. al. 1992].

One lesson from research on case-based design aids is that, to be useful in practice, design knowledge needs to be represented in multiple modalities, e.g., both conceptual and visual. This is typically done by annotating visual representations by conceptual knowledge (e.g., goals, plans).

4. AI techniques add precision to cognitive accounts of creative reasoning, and enable experimentation with them.

The two vertical spring systems shown here are identical except that the second spring has twice the coil diameter than the first. If the first spring stretches by some amount X when a mass M is applied to it, by how much will the second spring stretch when the same mass is applied to it?



Clement collected verbal protocols from 11 graduate students: 4 solved the problem; 2 others came close.

Nersessian conducted a cognitive analysis of the protocols based in part on the notion of limiting-case analysis.

The AI program called TORQUE [Griffith, Nersessian, Goel 1996, 2000] is a cognitive model of the graduate students' problem solving. It uses SBF models to represent its understanding of spring systems, flexible rods, etc. It uses a control architecture called Task-Method-Knowledge [Murdock and Goel 2001] for limiting-case analysis, and for analogical reminding and transfer.

Torque can imitate the reasoning of the 4 graduate students who solved the problem.

But, more importantly, simply by changing the initial knowledge conditions, it can also imitate the reasoning of the 2 students who came close to solving the problem (but failed to solve it).

5. AI techniques can generate new hypotheses about cognitive issues.

Innovation is intrinsically multimodal: it involves both conceptual knowledge in the form goals, plans, patterns (for example), and visual knowledge in the form of drawings, diagrams (for example).

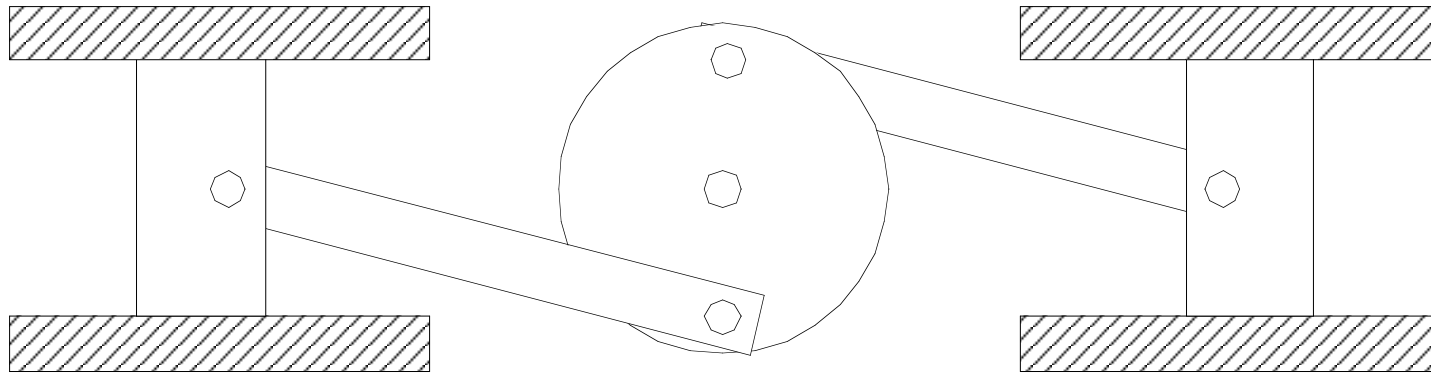
But what precisely is the coupling between visual and conceptual knowledge in design?

How do designers shift from visual reasoning to conceptual reasoning, and back, seemingly so effortlessly?

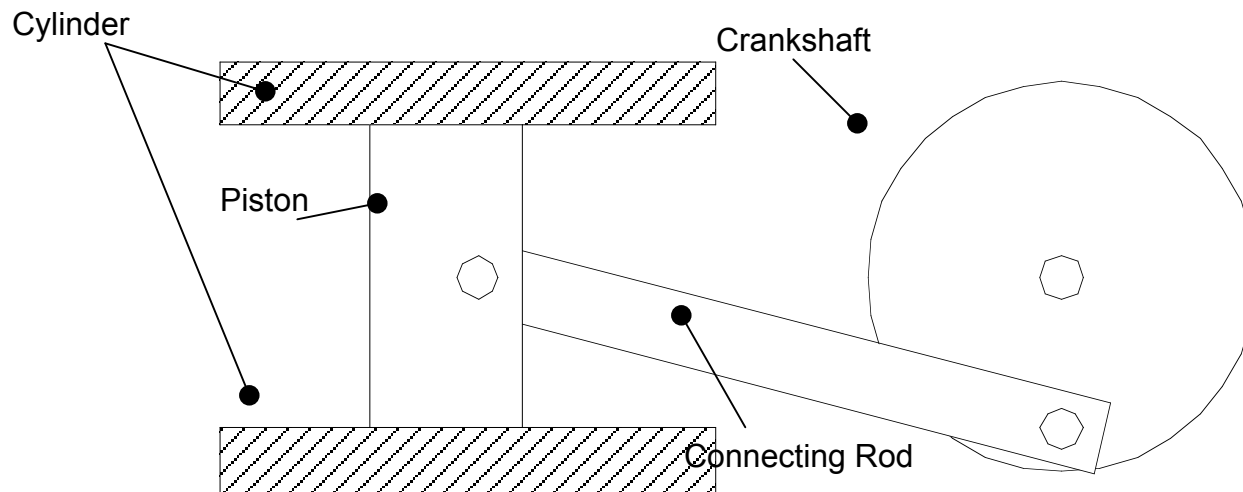
How do designers use one kind of knowledge (say, conceptual knowledge) to guide reasoning in another representational modality (visual reasoning)?

Target Drawing:

What is this device? What is its function? Its behavior?

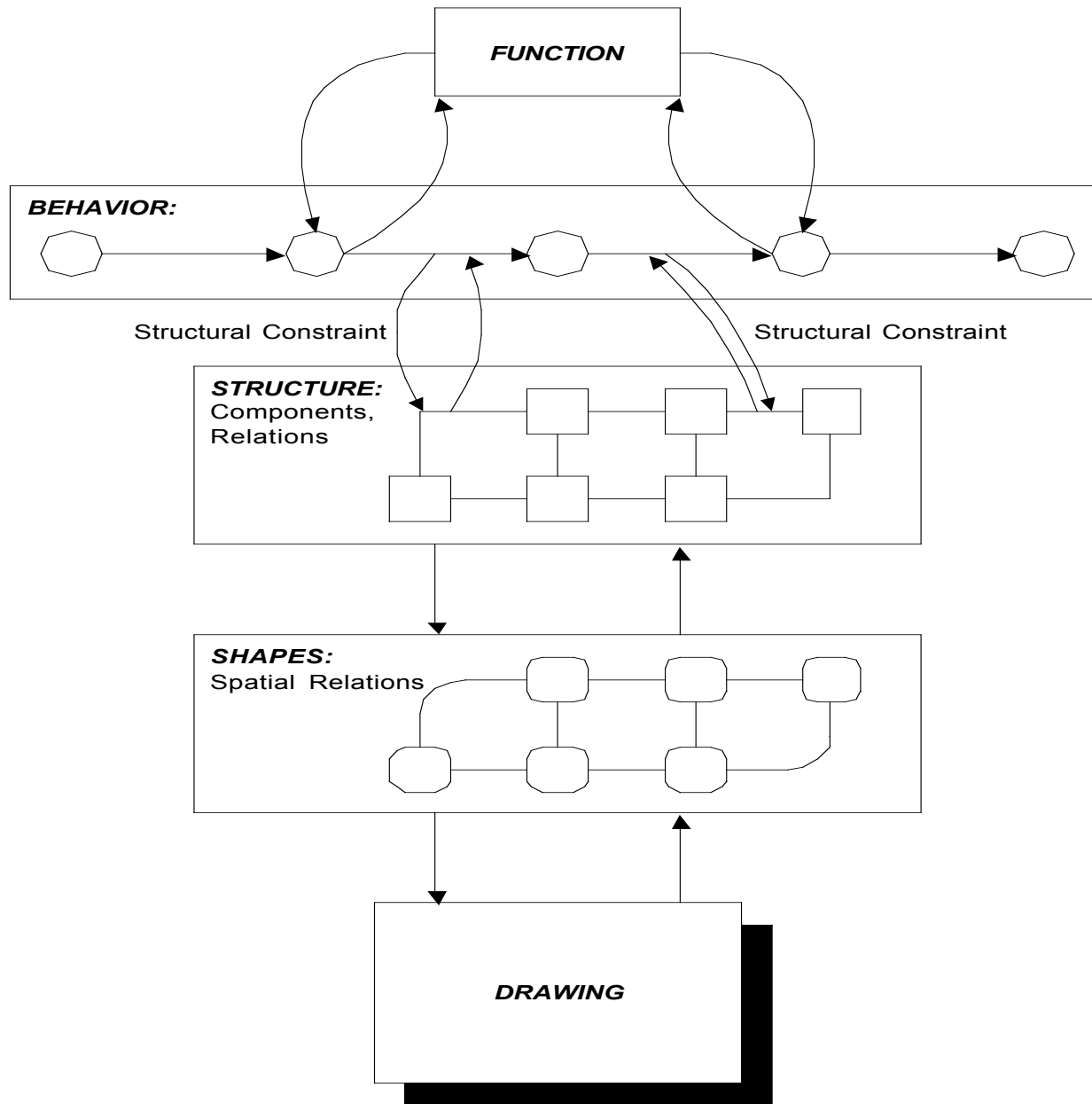


But now suppose a source drawing:

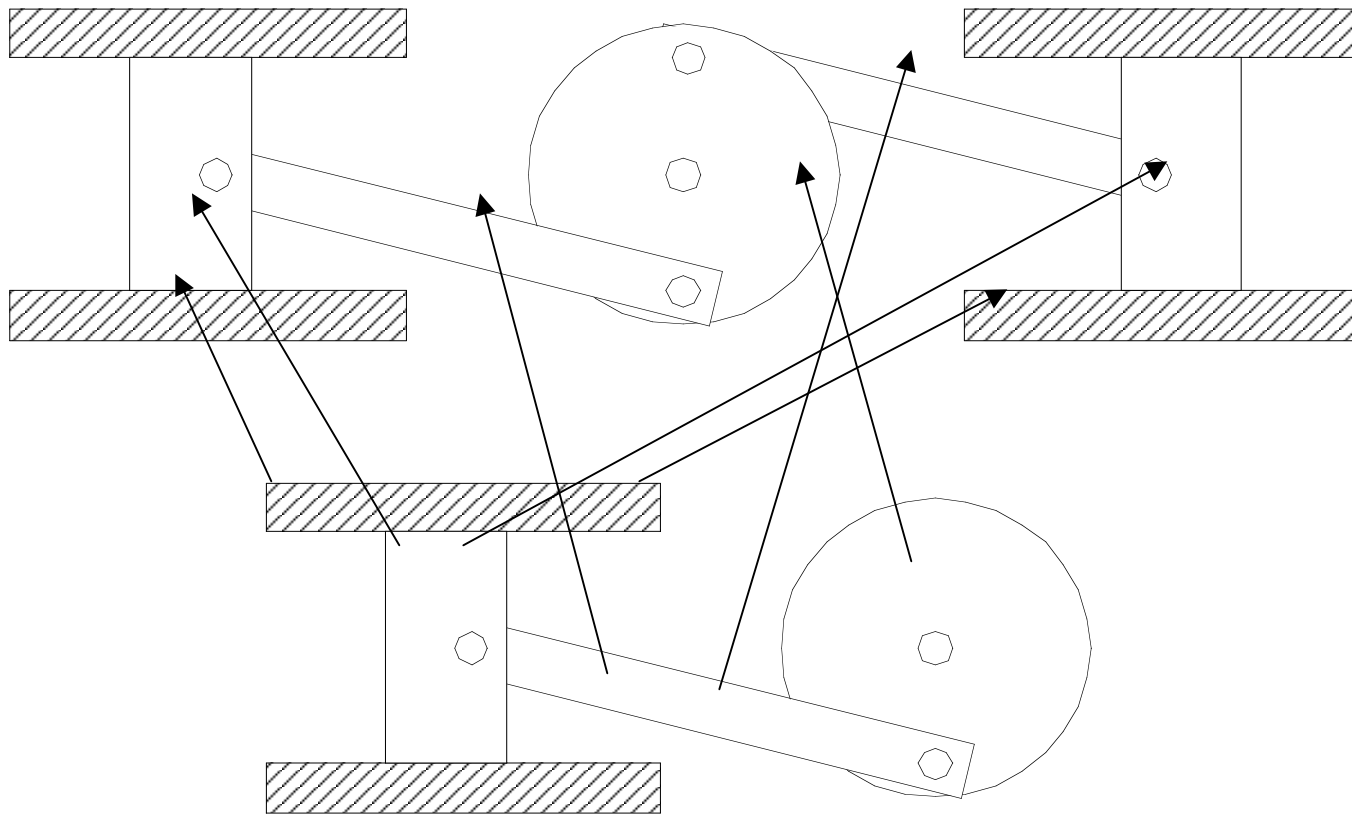


But now suppose an SBF model of the source drawing.

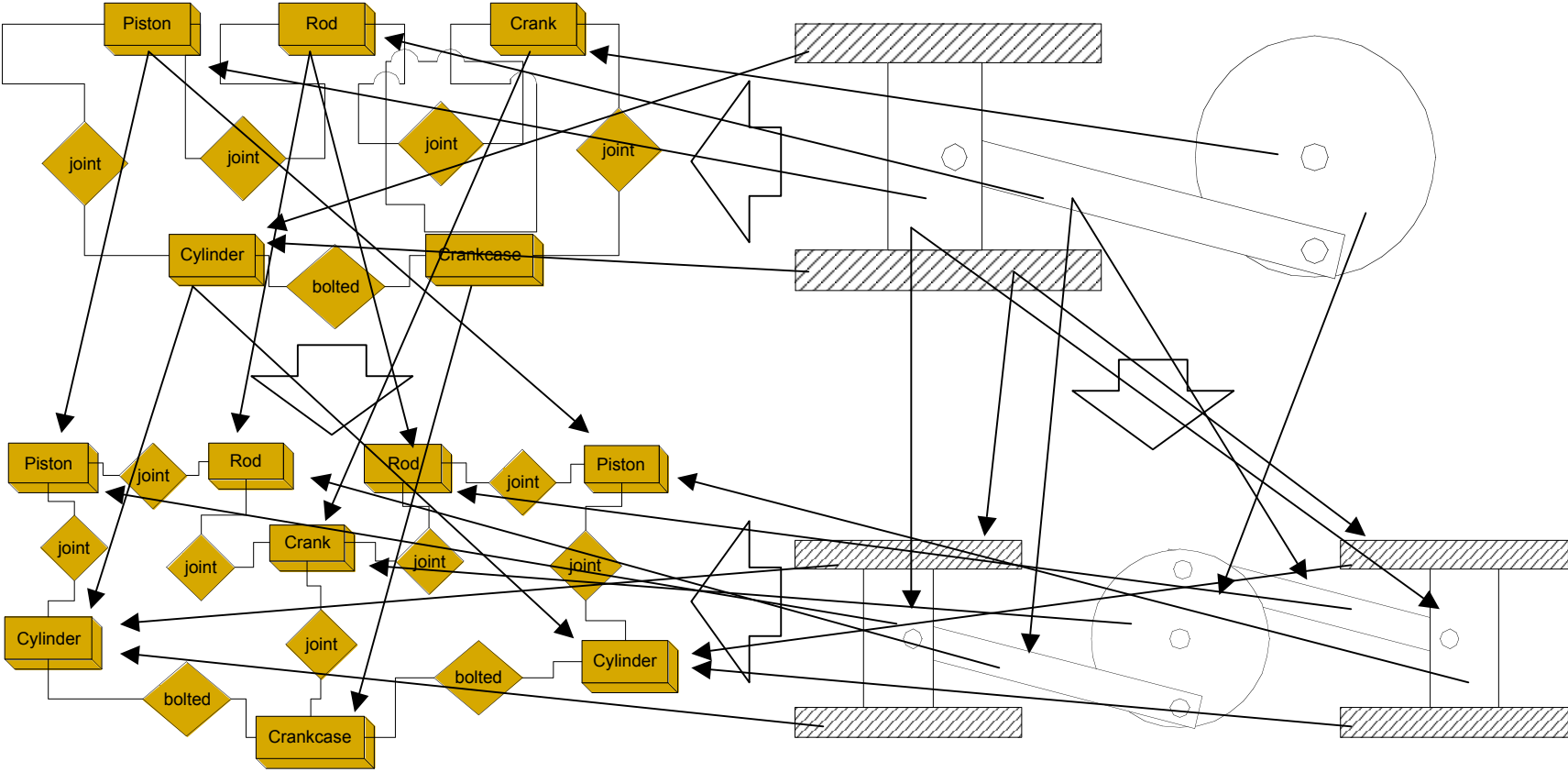
Drawing-Shape-Structure-Behavior-Function (DSSBF) Models



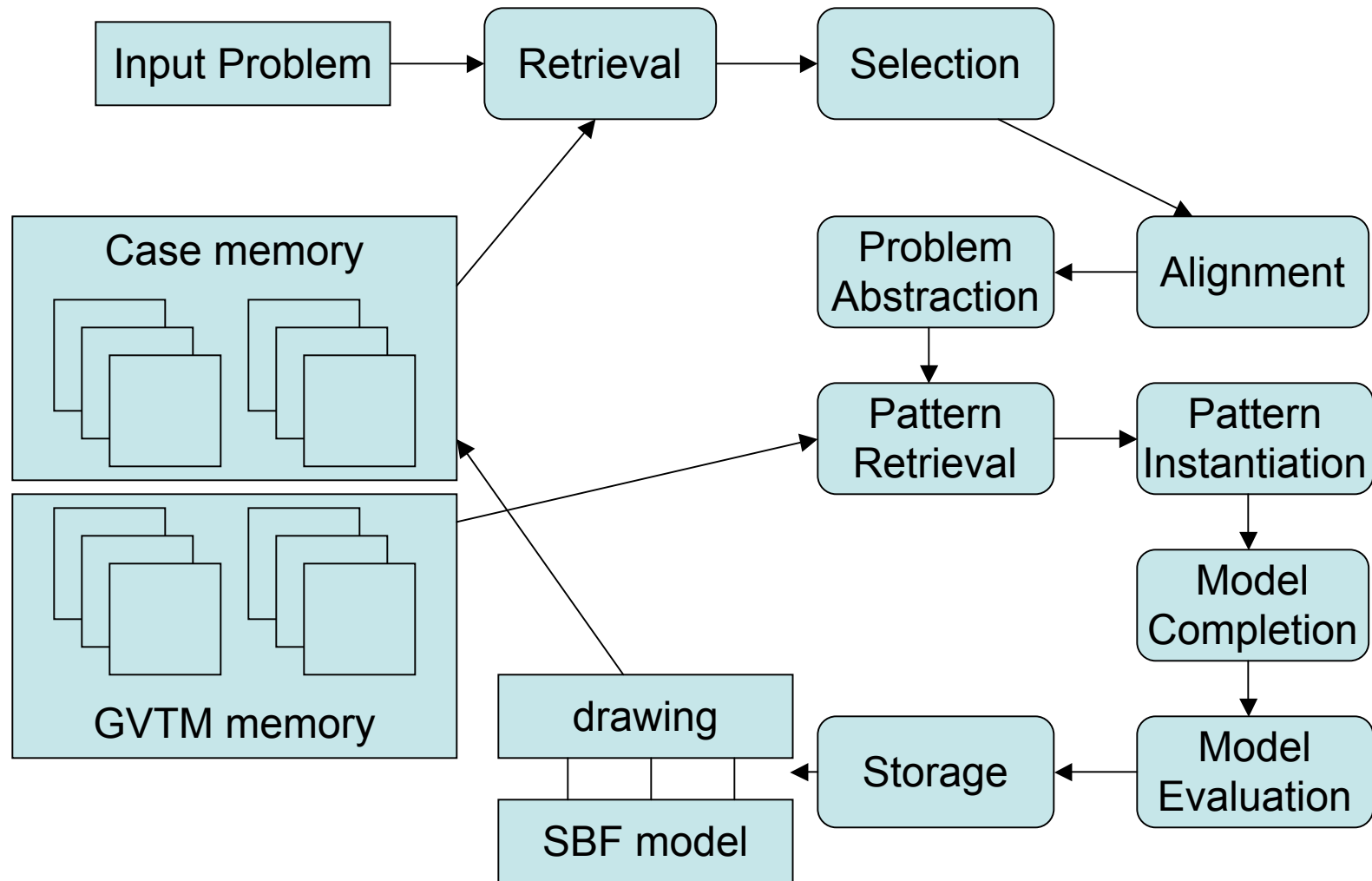
Retrieval and Mapping



Transfer and Adaptation



Process Outline



Conclusions?

Much of innovation occurs in the preliminary phases of design.

Mechanisms of innovative design include

1. Analogical reminding and transfer.
2. Transformations of the target problem.
3. Abstraction of design patterns.

These mechanisms are supported by mental models (e.g., SBF).

Mental models couple visual and conceptual knowledge (e.g., DSSBF), and enable integration of visual and conceptual reasoning.