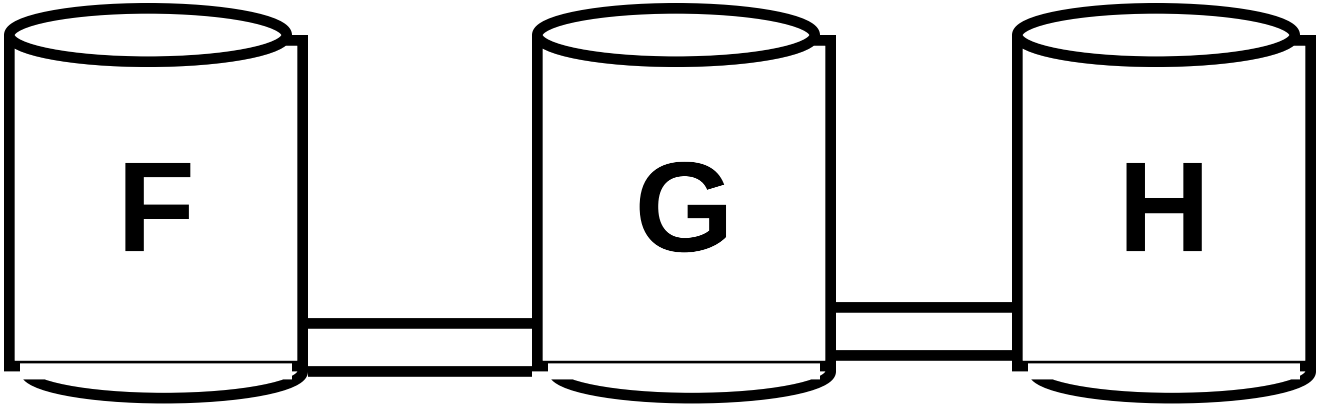
Implementing a qualitative reasoner: Part 2

EECS 344

Winter 2008

Why Qualitative Physics?

- Suppose someone tells you that the level in G is rising, and you want to figure out what could be happening.

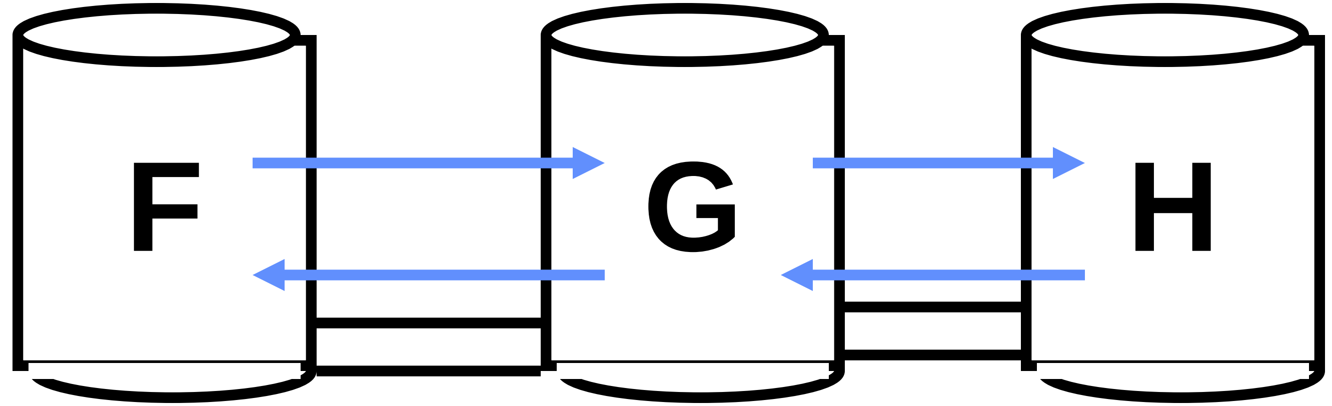


Qualitative Process Theory

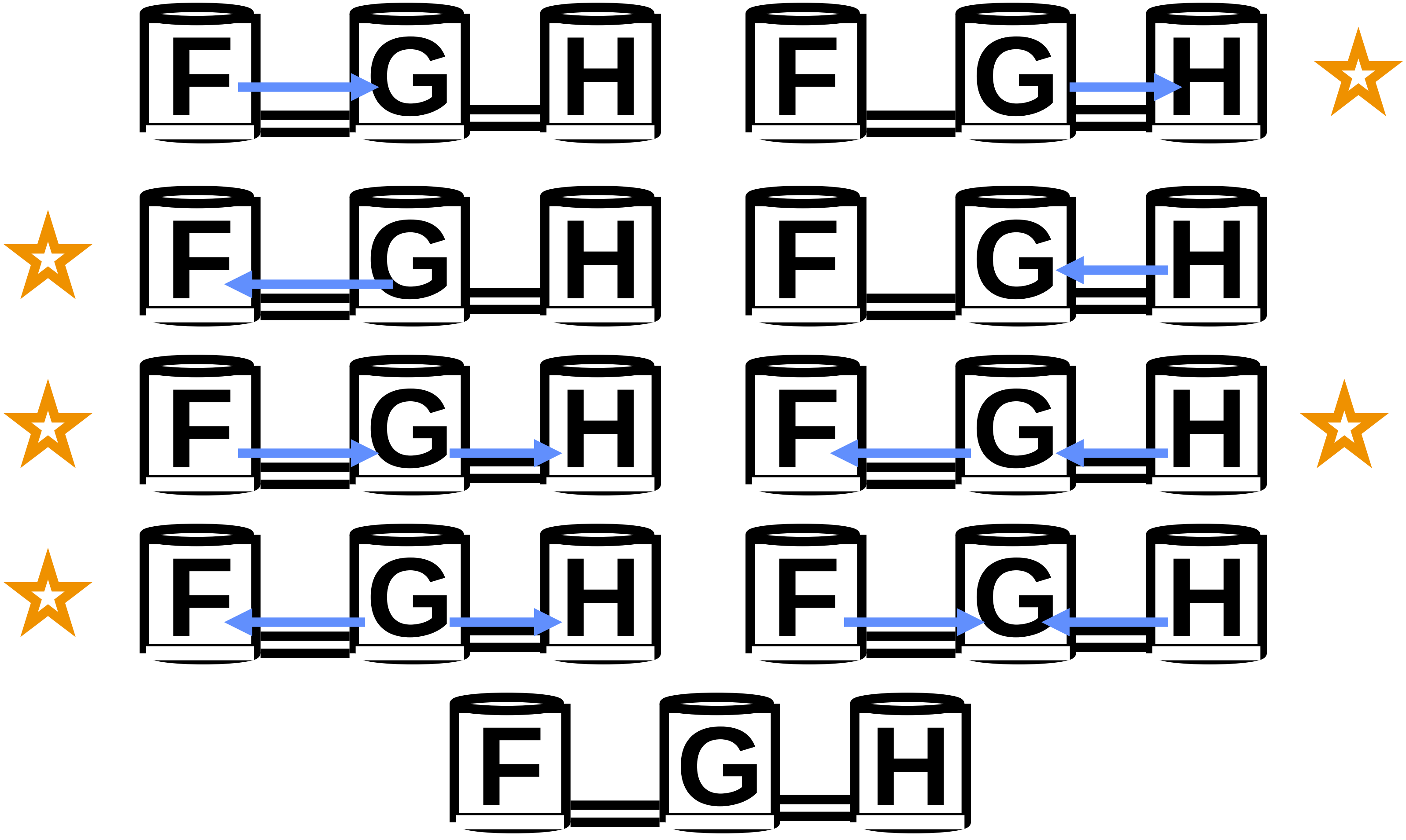
- Ontological Assumptions
- Mathematics
- Causal Account
- Organizing Domain Theories
- Basic Inferences

Example

Three possible contained stuffs, four potential fluid flows



Example



Design issues

- How should we represent changes over time?
- What should the modeling language look like?
- How do we build scenario models?
- How should inequality reasoning be performed?
- How should we search for interpretations?

Representing change over time

- In this task, we don't need to!
- Several good alternatives if we did:
  - Modal operators `(Holds p t)`
  - Slices `(> (P (at Wg t1)) (P (at Wg t2)))`
  - Implicit temporal notation
    `(> (P Wg) (P Wf))`

The Modeling Language

- `defprocess, defview` **to define entities and relationships that change over time**
- **Implement similarly to integration operators in JSAINT**
- **Need three other constructs as well**

defPredicate

- **Provides easy way to define the consequences of a predicate**
- **`(defPredicate <form> . <consequences>)`**

```
(defPredicate (heat-connection ?src ?path ?dst)
  (heat-path ?path) ;; inferred type
  (heat-connection ?dst ?path ?src)) ;; symmetric
```

defEntity

- **Provides a way of defining new entities**
- **Implication: Predication true if and only if the entity exists.**
- **(defEntity (*<predicate>* *<ind>*) . *<consequences>*)**

```
(defentity (Physob ?phob)
     (quantity (heat ?phob))
     (quantity (temperature ?phob))
     (> (A (heat ?phob)) ZERO)
     (> (A (temperature ?phob)) ZERO)
     (qprop (temperature ?phob) (heat ?phob)))
```

defRule

- Provides “glue” for other descriptions

```
(defrule <name> <triggers> . <consequences>)
```

```
(defrule Contained-Stuff-Existence
  ((Container ?can)(Phase ?st)(Substance ?sub))
  ;; Assume that every kind of substance
  ;; can exist in in every phase inside
  ;; every container.
  (quantity ((amount-of ?sub ?st) ?can))
  (>= (A ((amount-of ?sub ?st) ?can)) ZERO))
```

Subtle issue: Existence of quantities

- Continuous properties of things that don’t exist need to be treated differently.
  - The rat poison in your coffee.
  - The radiation level of the plutonium under your chair
- How do we easily link quantities to individuals?

Linking quantities to individuals

- **Declare them explicitly**

```
(defquantity-type (heat individual))
```

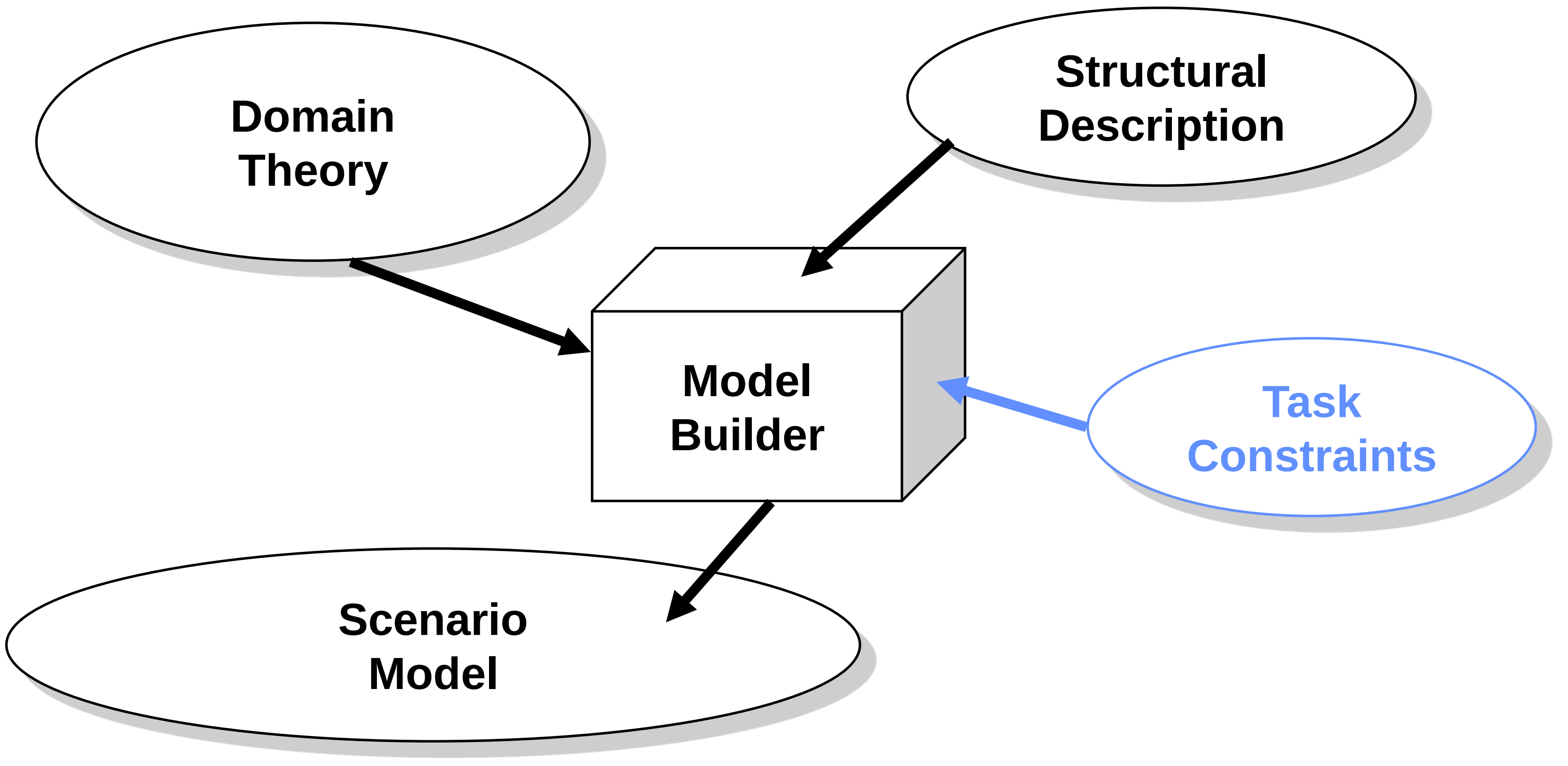
- **Force them to be unary**

```
(heat <fluid>)
```

- **Can *curry* to allow multiple arguments**

```
((amount-of-in <substance> <phase>) <container>)
```

Building Scenario Models



Working Assumptions

- All of the situation is relevant
  - No subsystems that can be ignored or isolated.
  - Can ignore my car’s electrical system when trying to fix a leak in the radiator.
- All of the domain theory is relevant
  - No phenomena that can be ruled out a priori.
  - Quantum tunneling as an explanation for why my car is using gas unusually quickly
- The domain theory will introduce only a finite number of individuals, given a finite structural description
  - Every physical object can be broken down into at least two parts, each of which itself is a physical object.

Solution: Instantiate everything

- Translate domain theory into LTRE rules.
- Enter structural description as assumptions (or assertions)
- Let LTRE sort it out.

The logic of processes

- **Let's take a look at the code...**
  - **`mlang.lsp` implements the constructs of the modeling language**
  - **`tnst.lsp` implements a sample domain theory.**

Efficient inequality reasoning

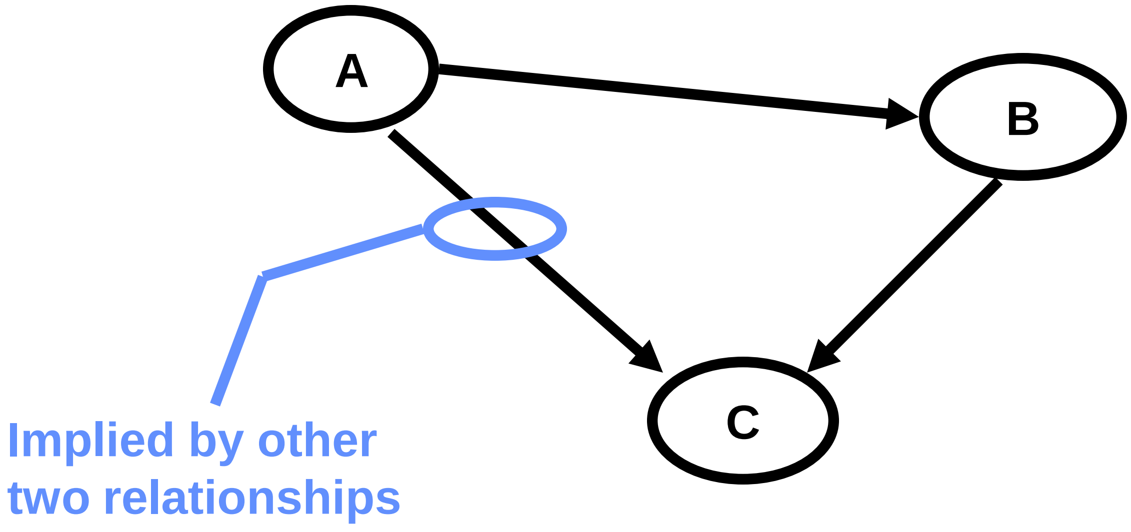
- **How not to do it:**

```
(rule ((:true (> ?n1 ?n2) :var ?>1))
  (rule ((:true (> ?n2 ?n3) :var ?>2))
    (rassert! (:implies (:and ?>1 ?>2)
                        (> ?n1 ?n3))
              :transitivity))
  (rule ((:true (= ?n2 ?n3) :var ?=1))
    (rassert! (:implies (:and ?>1 ?=1)
                        (> ?n1 ?n3))
              :transitivity)))
;; Plus two similar rules
```

- **Introduces new, unnecessary intermediate statements**

What’s really needed?

- Key observation: Only inequalities mentioned by some other part of the scenario model are relevant.
- Treat inequalities as a graph.
- All transitivity inferences correspond to cycles in the graph



Further Optimization: “Soft inequalities”

- **Obvious representation takes four statements**

$$A < B$$

$$A = B$$

$$A > B$$

$$A \perp B$$

- **Lots of redundancy**

How soft inequalities work

- **Really only need two statements per comparison:**

$$A < B \Leftrightarrow A \leq B \wedge \neg B \leq A$$

$$A = B \Leftrightarrow A \leq B \wedge B \leq A$$

$$A > B \Leftrightarrow \neg A \leq B \wedge B \leq A$$

$$A \perp B \Leftrightarrow \neg A \leq B \wedge \neg B \leq B$$

Let’s look at the inequality code

- `ineqs.lsp` defines the transitivity code

Searching for interpretations

- **What's an interpretation?**
  - **A set of active processes and their combined effects that predicts the observed data.**
- **A form of abductive inference**
  - **"If these processes were acting, and this change went this way instead of that, then we'd get what we are seeing."**
  - **Given B, A implies B, infer A.**
- **Constraint: Want the most plausible interpretation.**
  - **The level is rising because gravity within the container just changed its sign**

How to search process structures?

- Use dependency-directed search
- But over what?
  - set of preconditions and quantity conditions?
  - set of active processes and views?
- Many combinations of preconditions and quantity conditions have equivalent process structures
- Simpler to organize search around set of active views and processes.

How the search is organized

- Driver routine that organizes everything else
  - `mi.lisp`
- Generation of all process structures and view structures
  - `psvs.lisp`
- Resolve influences for each
  - `resolve.lisp`
- Recording complete states
  - `states.lisp`

Let’s look at the search code...

Resolving Influences

- **Find construals for the sets of influences on all quantities**
  - **`SETUP-IR`**
- **Impose a causal ordering on all the quantities**
  - **`FIND-INFLUENCE-ORDERING`**
- **Starting with direct influences, attempt to resolve all quantities.**
  - **`RESOLVE-INFLUENCES-ON`**
- **Use dependency-directed search to find consistent choices when ambiguity arises**
  - **`RESOLVE-COMPLETELY`**

We won’t look at the influence resolution code

- You’ll do that as part of your homework

Implementing QP Laws

- **Use PDIS rules to implement simple universal laws**
- **Use PDIS rules to provide “glue” linking lisp procedures to the rest of the system.**
- **Let’s examine `laws.lisp`...**

Some design observations

- **Sophisticated non-monotonic reasoning is quite feasible**
  - ***qualification problem*** **(what can affect a situation) solved by theory of what kinds of mechanisms can be causes.**
  - ***frame problem*** **solved by presuming that things only change when caused.**
  - **Logicians running behind practice, as usual**

Tradeoff: What's in rules versus procedures?

- **Some decisions cannot be made locally**
  - **Closed world assumptions**
- **Need flexible control structures that can make global decisions**
  - **Surely there is something better than Lisp code for this!**

Migration of rules to special-purpose code

- Examples
  - Reasoning about ordinal relations
  - Influence resolution
- Do “obvious” implementation first
- Optimize only when you know where the bottlenecks are

Habitability

- **Make formats for knowledge as implementation-independent as possible**
- **Make readable output and reports early**
- **When the going gets tough, the tough get GUI**

Homework 6

- **Assigned 2/14/08**
- **Due by start of class 2/21/08**
- **Please use subject line HW6**
- **From *Building Problem Solvers*, Chapter 11:**
  - **Problem 3**
  - **Problem 13**
  - ***Extra credit:* Problem 10**