13.

Qualitative Reasoning

CS227

Spring 2011

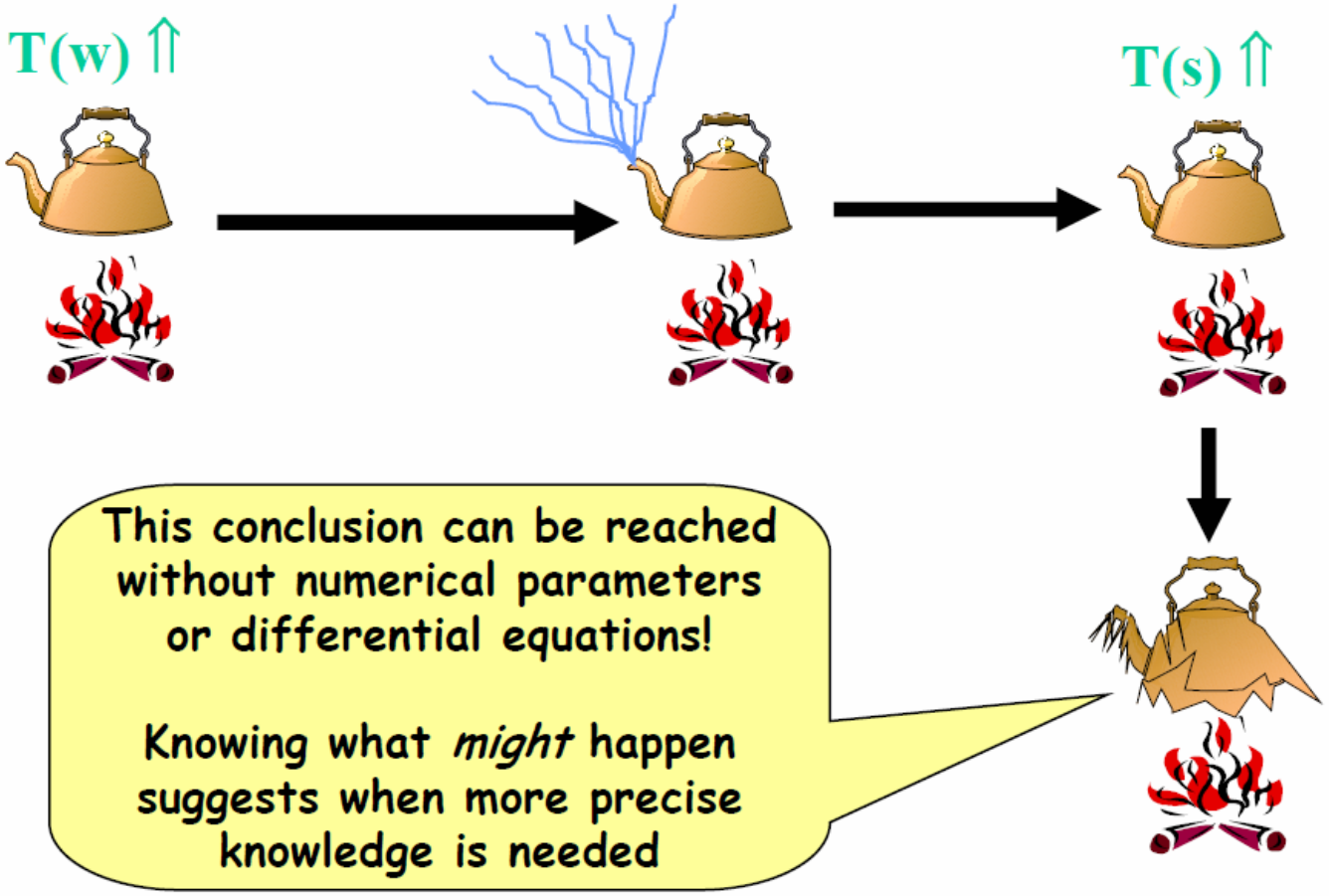
Example

- What can happen when you leave a tea kettle on a stove unattended for an hour?

Slide credit: Ken Forbus

Example

- What can happen when you leave a tea kettle on a stove unattended for an hour?

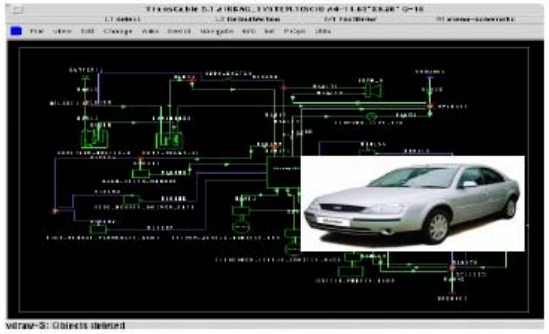


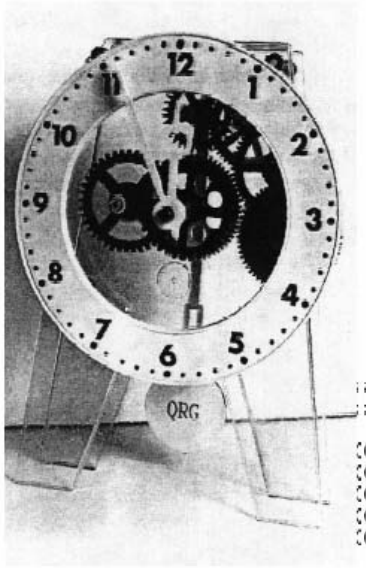
Slide credit: Ken Forbus

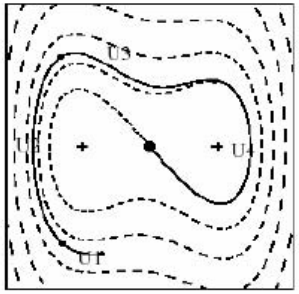
Qualitative Reasoning

- A means to express conceptual knowledge such as the physical system structure, causality, start and end of processes, assumptions and conditions under which facts are true, qualitatively distinct behavior, etc. (Bredeweg et. al. 2009)
  - Motivated by human cognition

Applications



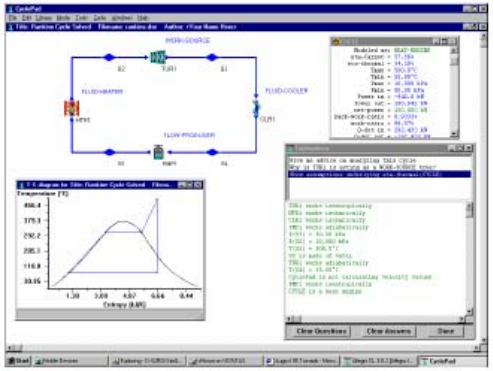





```
;; The Synthesized Control Law specifying the time instance, switching
;; state, and corresponding control value for each switching:

((time 0.) (switching-state #(-1 -3)) (control .2))
((time .284) (switching-state #(-1.82 -2.71)) (control 0.))
((time 1.06) (switching-state #(-1.86 2.49)) (control -.2))
((time 2.71) (switching-state #(1.35 1.82)) (control 0.))
((time 6.76) (switching-state #(-.0023 -.0692)) (control *local-control*))
```

Monitoring, diagnosis,
failure modes and effects analysis,
creating control software,
explanation generation,
tutoring…



Slide credit: Ken Forbus

Outline

- Introduction to qualitative reasoning
  - Through the Redime project
- Qualitative representation and reasoning
- Qualitative spatial reasoning
- Summary

Introduction to Qualitative Reasoning

- Introductory video
  - http://hcs.science.uva.nl/QRM/Garp3NNR.mov

Principles of Qualitative Representation

- Discretization
  - Represent continuous quantities using entities that can be reasoned symbolically providing a way to do abstraction
    - Instead of using a numerical value for rate of change, consider whether it is increasing, decreasing or constant
- Relevance
  - Choose qualitative values based on relevance to a task
    - If temperature is changing, boiling point may be important
    - If temperature is constant, boiling point may be irrelevant
- Ambiguity
  - Abstraction leads to ambiguity
    - Instead of providing one answer, provide a range of answers

Qualitative Process Representation and Reasoning

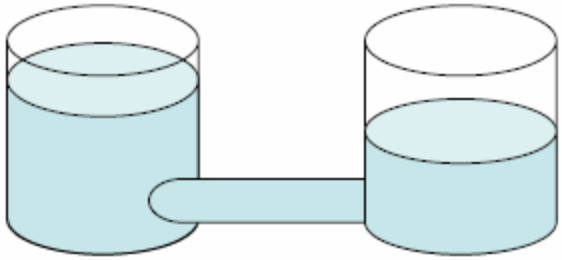
- Structure
- Behavior
- Aggregate
- Simulation

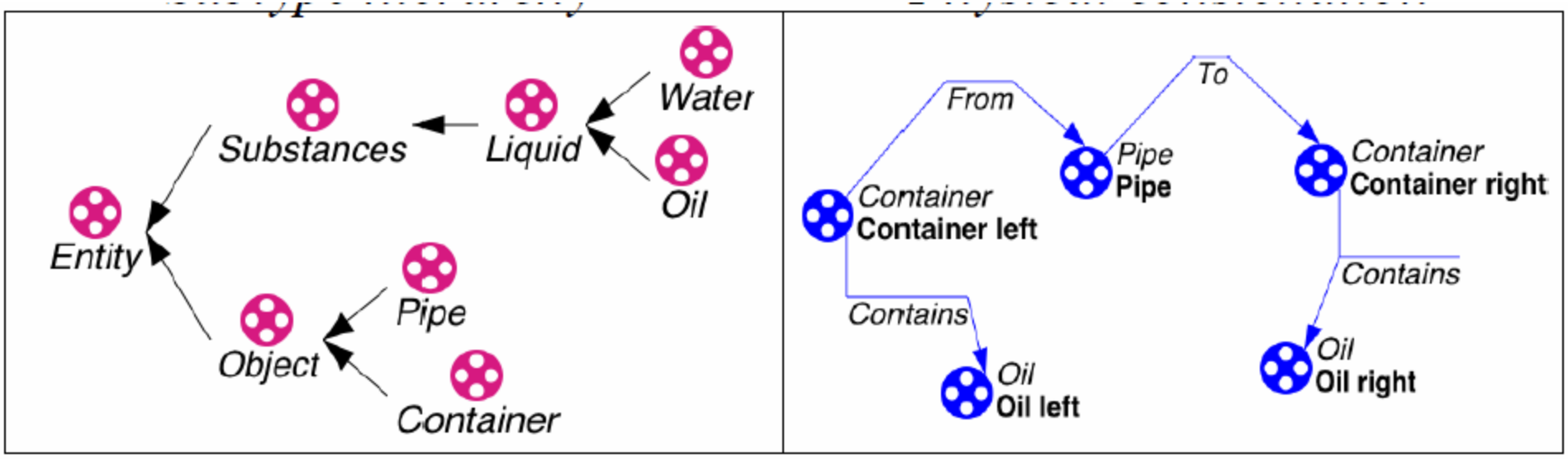
  - We will consider each of these in more detail with examples
  - The detailed definitions of these can also be viewed as an ontology of qualitative reasoning

Structure

- Entities
  - Physical objects or abstract concepts that constitute the system
  - Their relevant properties are represented as quantities that may change under the influence of processes
- Agent
  - Entities outside the modeled system
  - Agents can have quantities that influence the system
    - Such quantities are called exogenous quantities
- Assumptions
  - Conditions that are presumed to be true
- Configuration
  - Relations between instances of entities and agent

Example





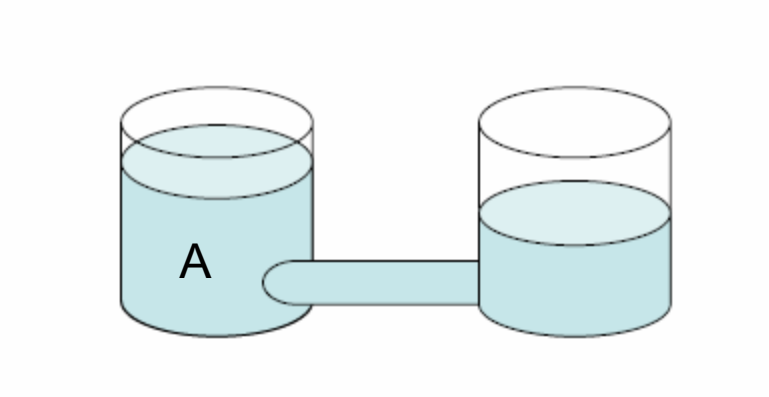
Slide credit: Bert Bredeweg

Behavior

- Quantity
  - Quantity Space
  - Magnitude and derivative
- Direct influence
- Proportionality
- Correspondence
- Inequality

Quantity

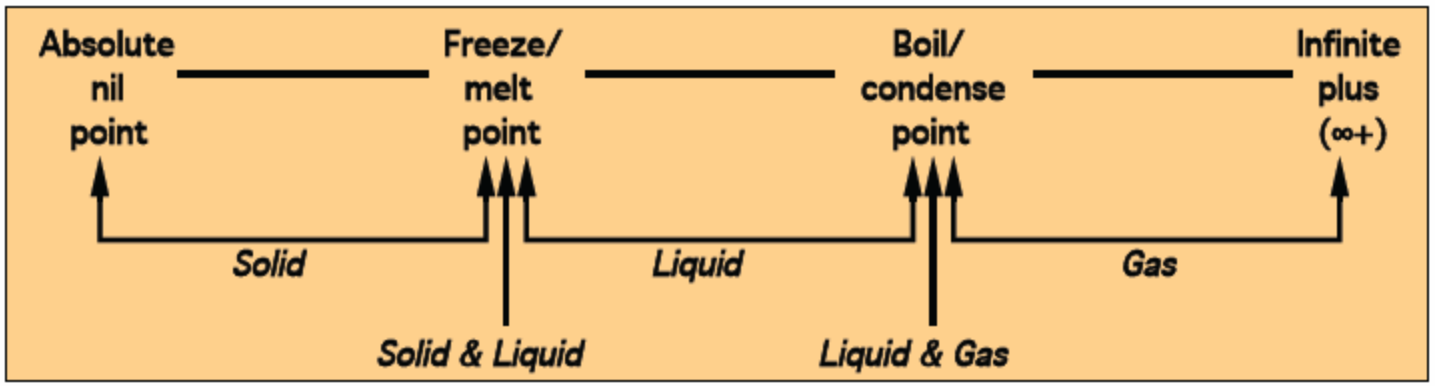
- Quantities represent changeable features of entities and agents.
  - Represented by their quantity value which consists of magnitude and derivative
    - Quantity space specifies the range of possible values for a quantity
    - Magnitude indicates the current value of a quantity
    - derivative indicates how the quantity is changing (can be +, -, 0)



Quantity:
height_A
Quantity Space:
0, plus, max
Derivative
-

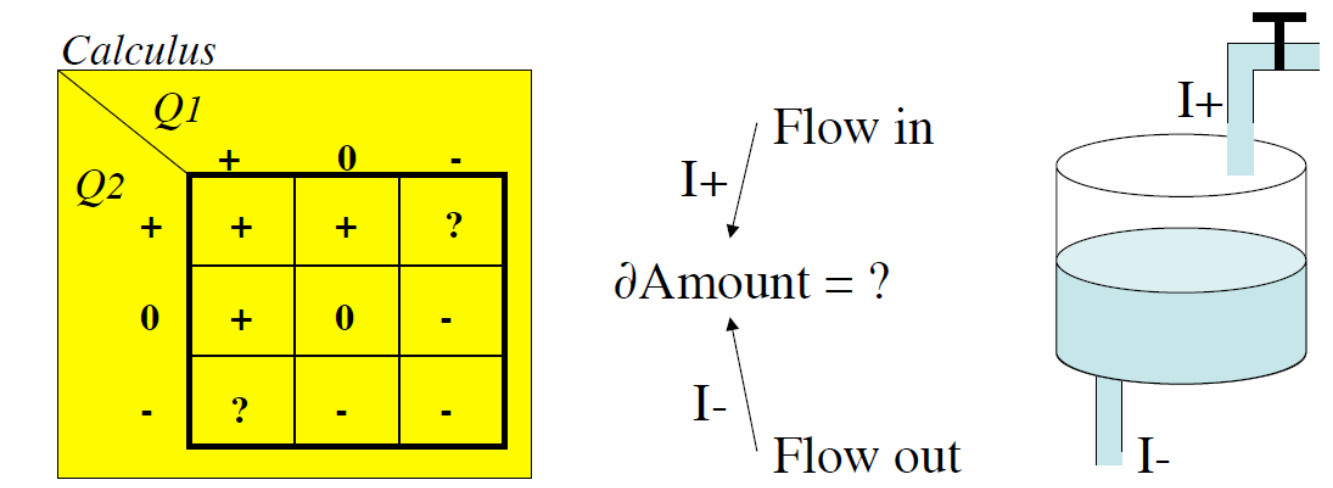
Quantity

- The quantity space representation needs to be chosen based on the application needs
  - Need to introduce landmarks



Direct Influence

- Directed relations between two quantities
  - Can be either positive (I+) or negative (I-)
  - Cause of change within a model, and therefore, model processes
  - Magnitude of influencing quantity determines the rate of change of affected quantity

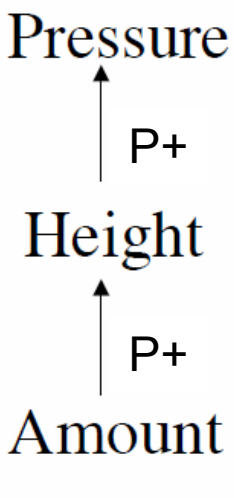


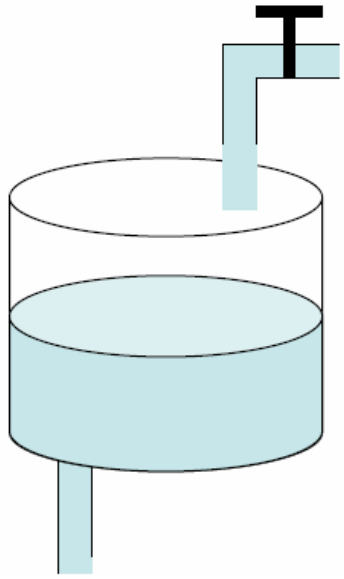
Proportionality

- Directed relations between two quantities
  - Propagate effects of processes
  - Set the derivative of the target quantity depending on the target of the source quantity

Calculus

Q2 \ Q1	+	0	-
+	+	+	?
0	+	0	-
-	?	-	-





Correspondence

- Relations between qualitative values of different quantities and can be either *directed* or *undirected*
  - *Directed:* When value A of quantity X corresponds to value of quantity Y, we can derive that Y has value B when X has value A

Example:

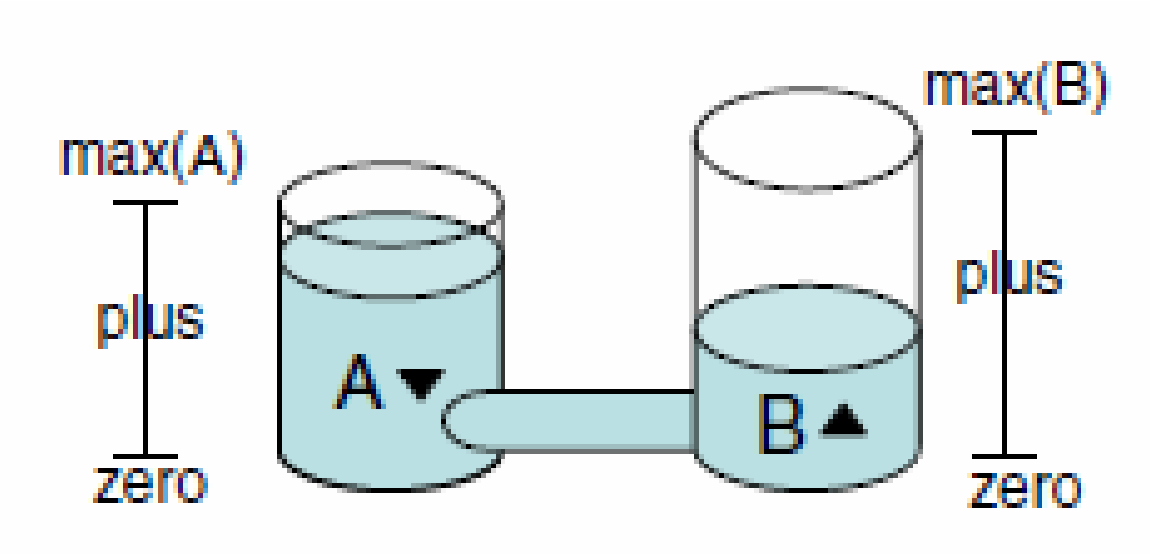
When size of population is zero, the birth rate is also zero

When size of population is large, the biomass is large

Inequality

- Inequalities specify (<,≤ , =,≥, >) an ordinal relation between two items
  - Between magnitudes
    - A quantity and a value from quantity space
      - Temperature is at boiling point
    - Magnitude of two quantities
      - Temperature of substance A > temperature of substance B
    - Values from the quantity spaces of two quantities
      - Boiling point water < boiling point of oil
  - Between derivatives

Example Inequalities



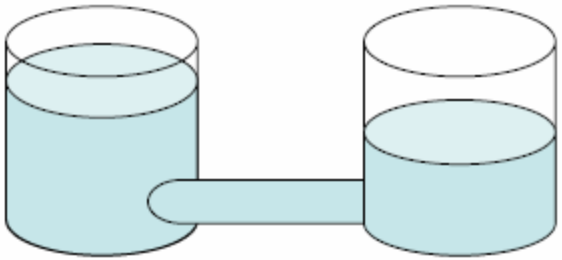
$A > B$
$A > Zero$
$B > Zero$
$A < Max(A)$
$B < Max(B)$
$Max(A) > Max(B)$
$Zero < Max(A)$
$Zero < Max(B)$
$\delta A < \delta B$
$\delta A < Zero$
$\delta B > Zero$

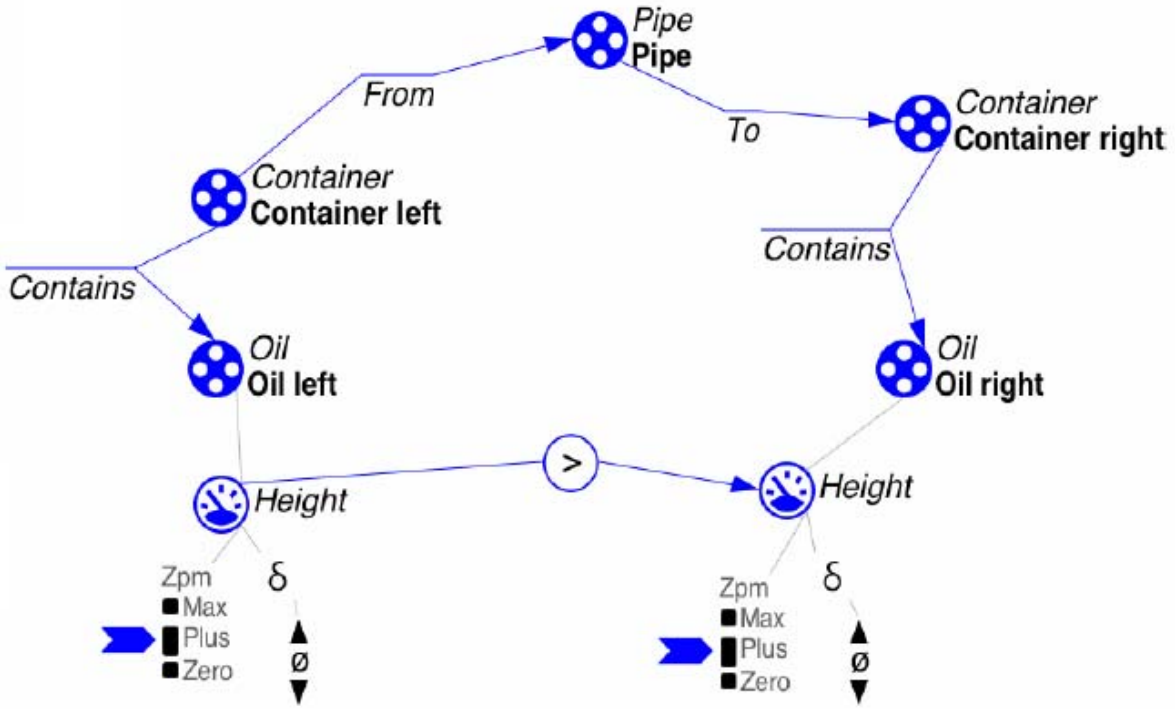
Aggregate

- Scenario
- Model fragment

Scenario

- Describe the initial state of the system



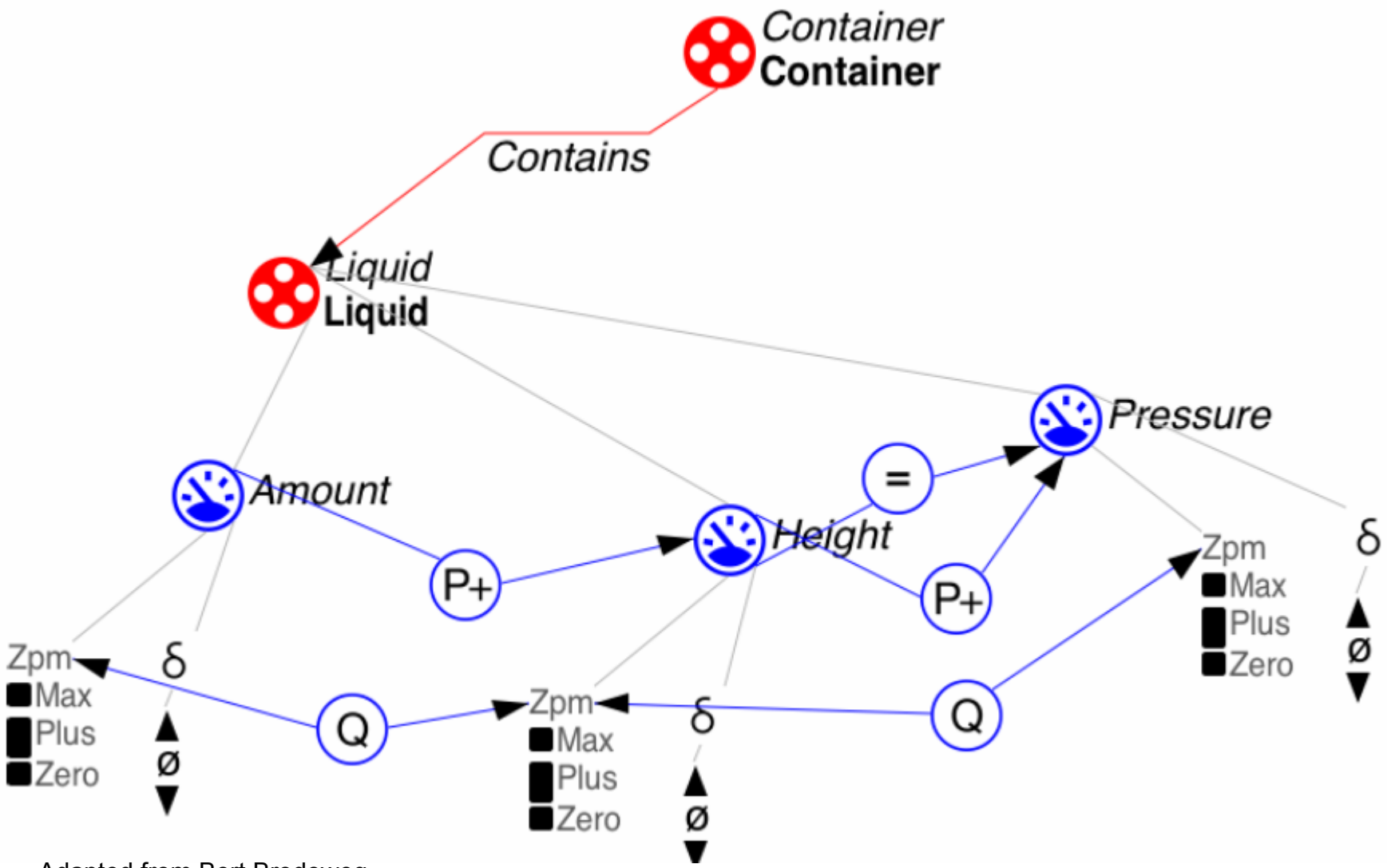


Adapted from Bert Bredeweg

Model Fragment

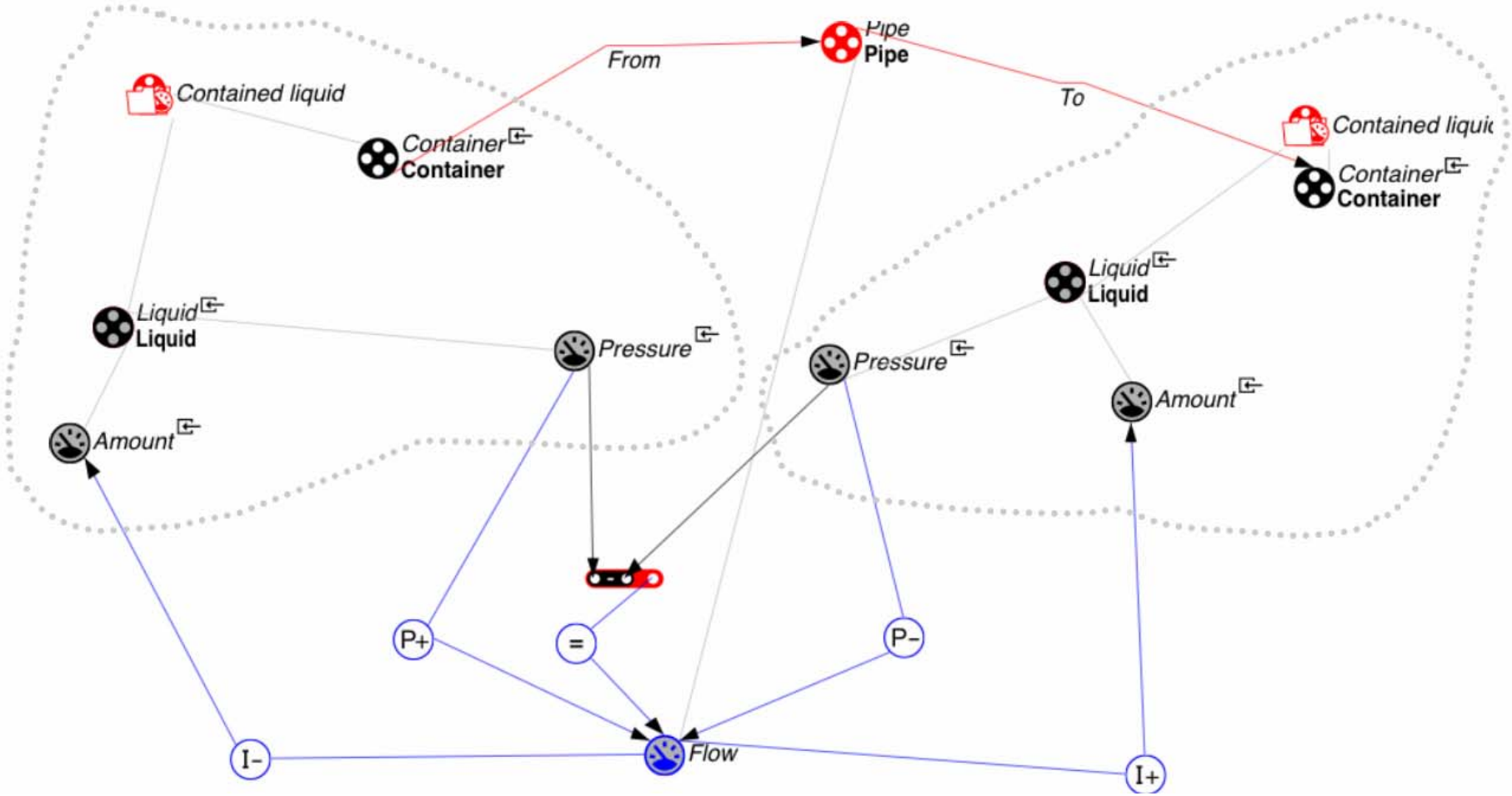
- Describe part of the structure and behavior of the system in a general way
  - Can be thought of as rules
    - Can be represented as conditions or consequences
  - Three kinds of fragments
    - Static: Structure of the system and the proportionalities
    - Process: Contain at least one direct influence
    - Agent: contain an agent, ie, an element external to the system; may not be influenced by the system but could influence it

Static Model Fragment



Adapted from Bert Bredeweg

Process Model Fragment

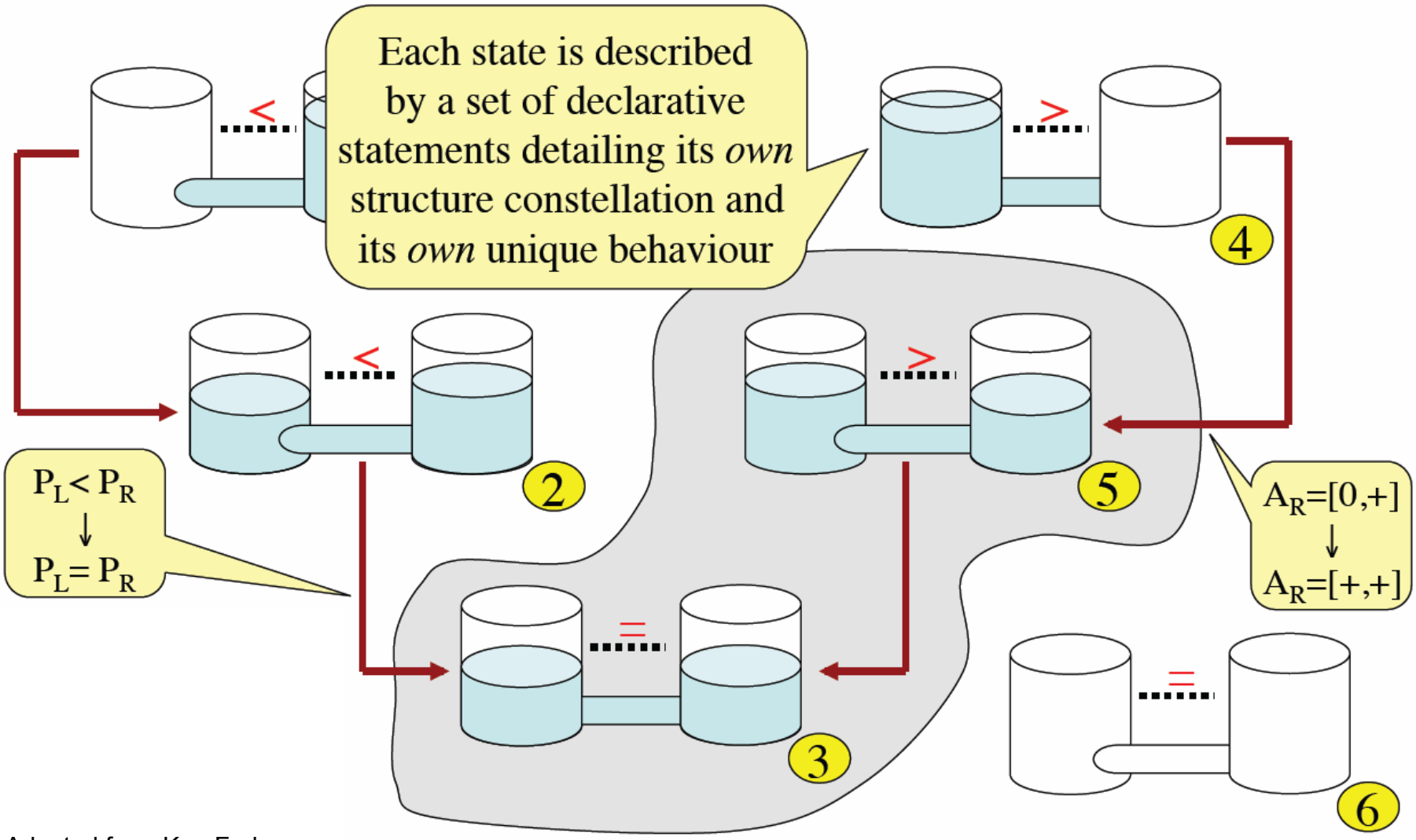


Adapted from Bert Bredeweg

Qualitative Simulation

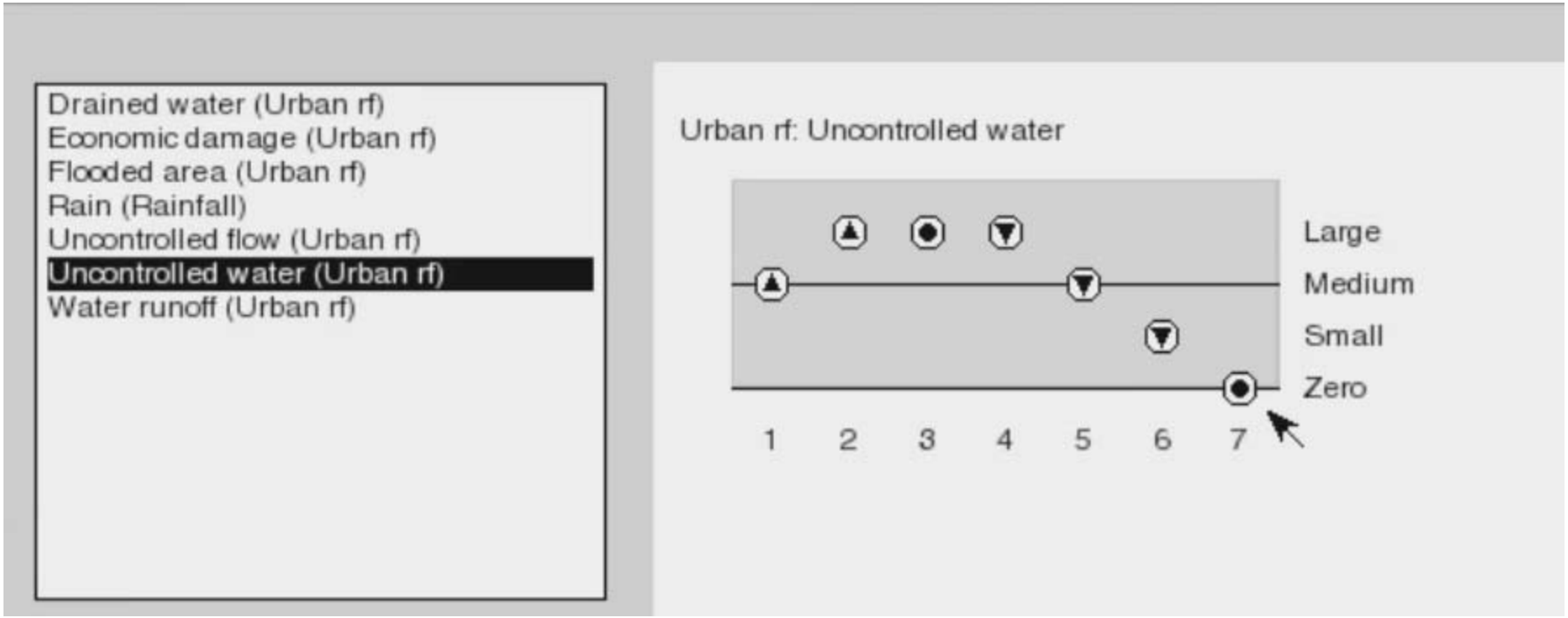
- State
  - Describes a particular situation of a modeled system reflecting qualitatively unique behavior
- State-graph
  - A set of states and the possible transitions among thme
- Value history
  - Shows how quantity values change
- Equation history
  - Shows how the ordinal relations change
- Causal model
  - Describes how quantities are causally related

State Graph



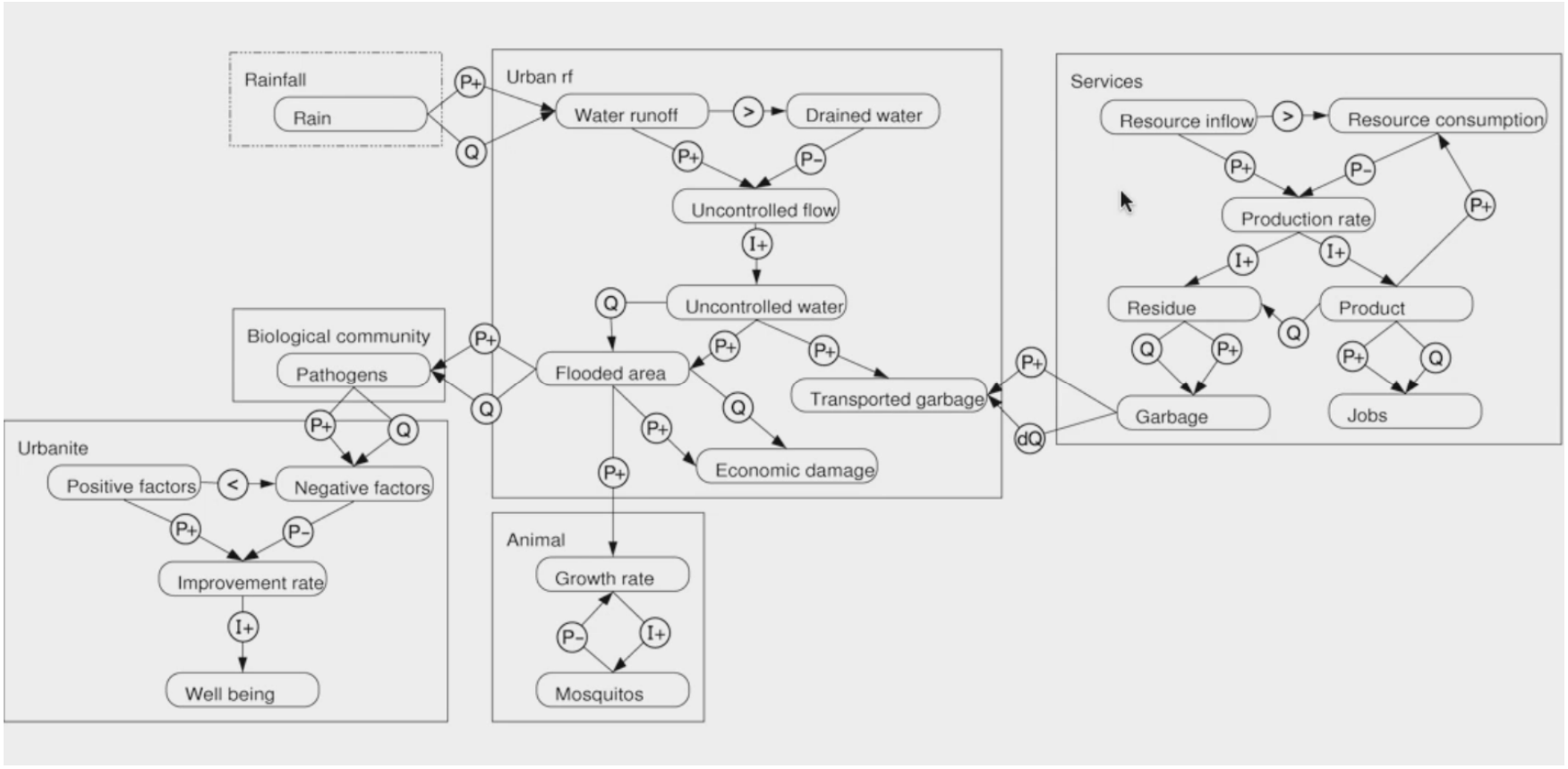
Adapted from Ken Forbus

Quantity Value History



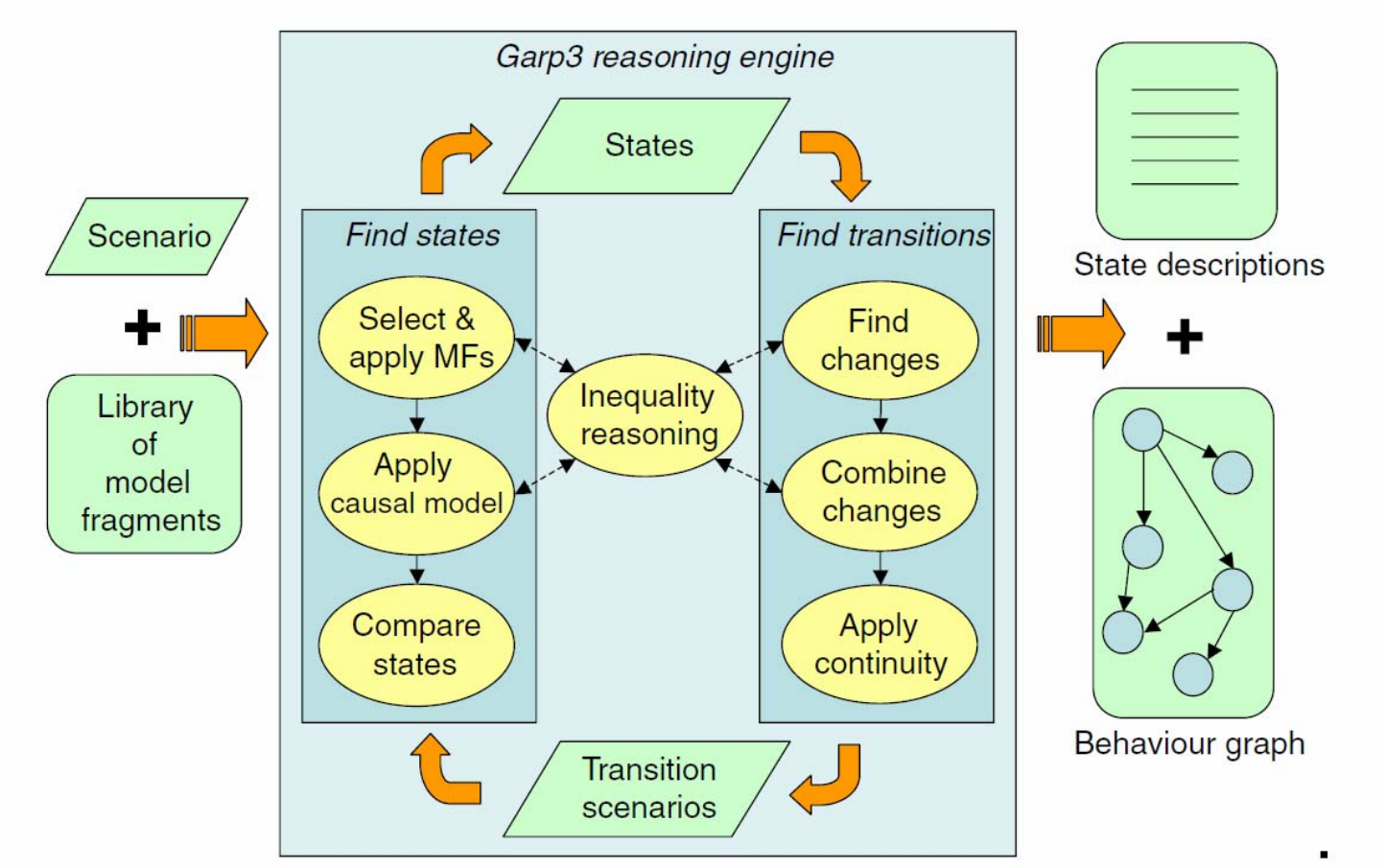
Adapted from Bert Bredeweg

Qualitative Causal Model



Adapted from Bert Bredeweg

Qualitative Reasoning



Adapted from Bert Bredeweg

Qualitative Reasoning

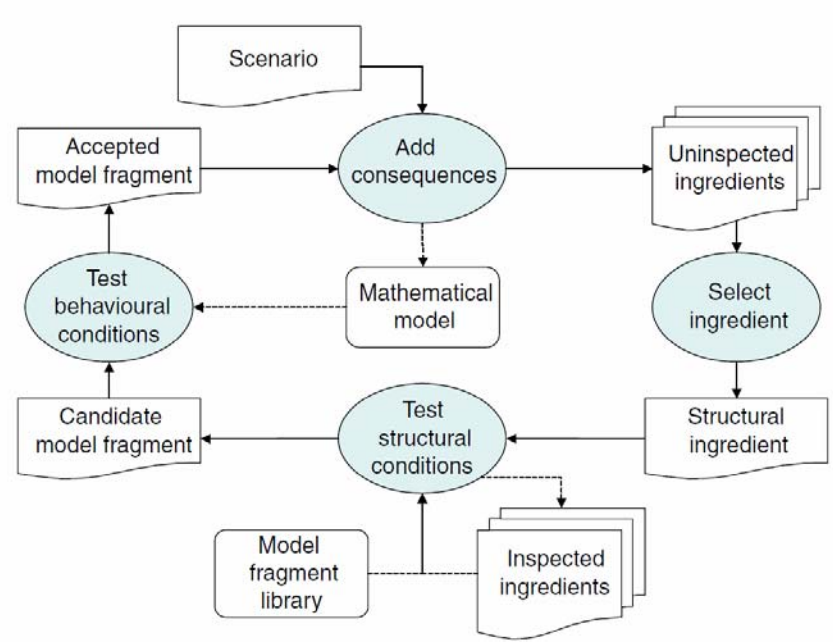
- Three main elements
  - Find states
  - Find transitions
  - Inequality reasoning

Find States

- Select and apply model fragments
- Determine state dynamics
- Compare states

Select and Apply Model Fragments

- Ingredients
  - Structural (entities, agents, …)
  - Behavioral (value, inequality, …)
  - Causal (influence, …)
- Check behavioral conditions
  - Known: apply
  - Contradiction: reject
  - Unknown: check later
- Assumptions can be made
- Consequences are applied



Determine State Dynamics

- Account for exogenous effects
- Influence resolution
  - ∑I+ rel ∑I- (where rel ϵ {>, ≥, =, ≤, <. ?})
  - ∑P+ rel ∑P- (where rel ϵ {>, ≥, =, ≤, <. ?})
  - Assumes that the processes involved have comparable effects

Find State Transitions

- Find model ingredients that may change and lead to termination of the state
  - transition of value to adjoining value in quantity space, etc
- Combine changes to assess the order in which terminations may happen and determine valid combinations
- Apply continuity rules to each combination to produce a complete transition scenario

Inequality Reasoning

- Based on
  - algebraic simplification
    - (sum1+V) rel (sum2+V) → sum1 rel sum2
  - anti-symmetry
    - (sum1≥sum2) &(sum2≥sum1)→sum1=sum2
  - transitivity
- Examples:

R1 & R2 →	$A=B$	$A\geq B$	$A>B$
$C=D$	$A+C=B+D$	$A+C\geq B+D$	$A+C>B+D$
$C\geq D$	$A+C\geq B+D$	$A+C\geq B+D$	$A+C>B+D$
$C>D$	$A+C>B+D$	$A+C>B+D$	$A+C>B+D$

$Ex2)\ P>Q,\ (Q=P)$ *(given)*
$(P>Q)\ \&\ Q=P\rightarrow P+Q>P+Q$ *(transitivity)*
$P+Q>P+Q\rightarrow 0>0$ *(simplification)*
Contradiction *(result)*

$Ex3)\ R>S,\ T>0$ *(given)*
$(R>S)\ \&\ (T>0)\rightarrow R+T>S$ *(transitivity)*
$R+T>S$ *(result)*

Adapted from Bert Bredeweg

Inequality Reasoning

- Triggered any time we
  - Add a new inequality relation or a new correspondence
- Inequality reasoning infers new relations and checks if it is
  - simplifiable
  - Not circular
  - Not derivable
  - Not evident
  - Not invalid
- If it passes all the tests, it is added to the set of known relations

Example Conclusions

- If we keep heating the kettle, it will eventually burn
- For two containers connected by a tube, there are 6 possible states
- Too much rain leads to mosquitoes if there is insufficient drainage

Summary of Qualitative Process Representations

- Qualitative representations
  - Proportionality, influences, correspondences, inequalities
- Qualitative reasoning
  - Simulation of states, influence calculus, inequality reasoning
- Captures important aspects of human reasoning
  - Can use partial and incomplete information
  - Supports causal reasoning

Outline

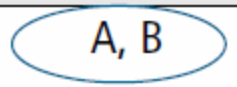
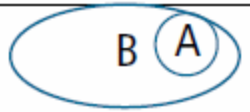
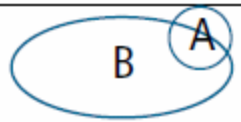
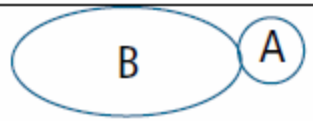
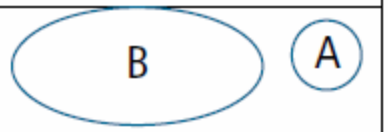
- Introduction to qualitative reasoning
  - Through the Redime project
- Qualitative representation and reasoning
- Qualitative spatial reasoning
- Summary

Qualitative Spatial Reasoning

- Two approaches
  - Purely qualitative spatial relationships
    - Topology, orientation, direction
  - Spatial representations needed for visual representations
    - Diagrams

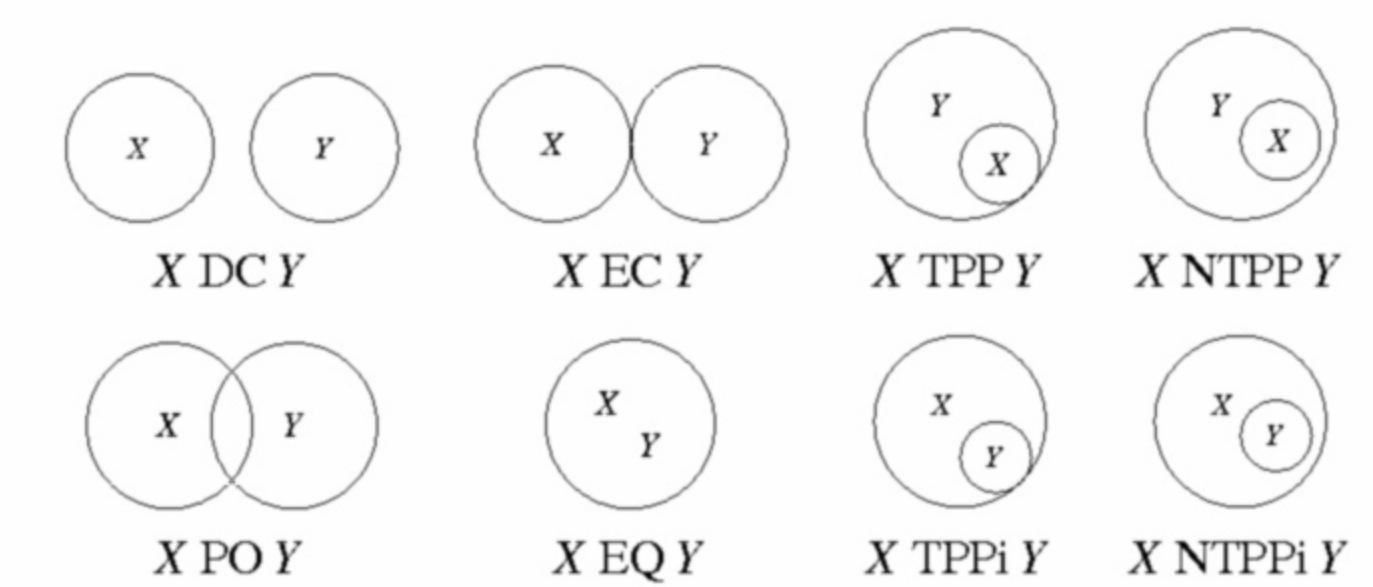
Topological Spatial Relations

- Jointly exhaustive pair wise disjoint relationships (JEPD)

Relationship	Example
= Equals	
NTPP Non-tangential proper part (plus its inverse)	
TPP Tangential proper part (plus its inverse)	
PO Partially Overlapping	
EC Edge connected	
DC Disjoint	

Transitive Reasoning

o	DC	EC	PO	TPP	NTPP	TPPi	NTPPi	EQ
DC	*	DC,EC,PO,TPP,NTPP	DC,EC,PO,TPP,NTPP	DC,EC,PO,TPP,NTPP	DC,EC,PO,TPP,NTPP	DC	DC	DC
EC	DC,EC,PO,TPPi,NTPPi	DC,EC,PO,TPP,TPPi,EQ	DC,EC,PO,TPP,NTPP	EC,PO,TPP,NTPP	PO,TPP,NTPP	DC,EC	DC	EC
PO	DC,EC,PO,TPPi,NTPPi	DC,EC,PO,TPPi,NTPPi	*	PO,TPP,NTPP	PO,TPP,NTPP	DC,EC,PO,TPPi,NTPPi	DC,EC,PO,TPPi,NTPPi	PO
TPP	DC	DC,EC	DC,EC,PO,TPP,NTPP	TPP,NTPP	NTPP	DC,EC,PO,TPP,TPPi,EQ	DC,EC,PO,TPPi,NTPPi	TPP
NTPP	DC	DC	DC,EC,PO,TPP,NTPP	NTPP	NTPP	DC,EC,PO,TPP,NTPP	*	NTPP
TPPi	DC,EC,PO,TPPi,NTPPi	EC,PO,TPPi,NTPPi	PO,TPPi,NTPPi	PO,TPP,TPPi,EQ	PO,TPP,NTPP	TPPi,NTPPi	NTPPi	TPPi
NTPPi	DC,EC,PO,TPPi,NTPPi	PO,TPPi,NTPPi	PO,TPPi,NTPPi	PO,TPPi,NTPPi	PO,TPP,NTPP,TPPi,NTPPi,EQ	NTPPi	NTPPi	NTPPi
EQ	DC	EC	PO	TPP	NTPP	TPPi	NTPPi	EQ



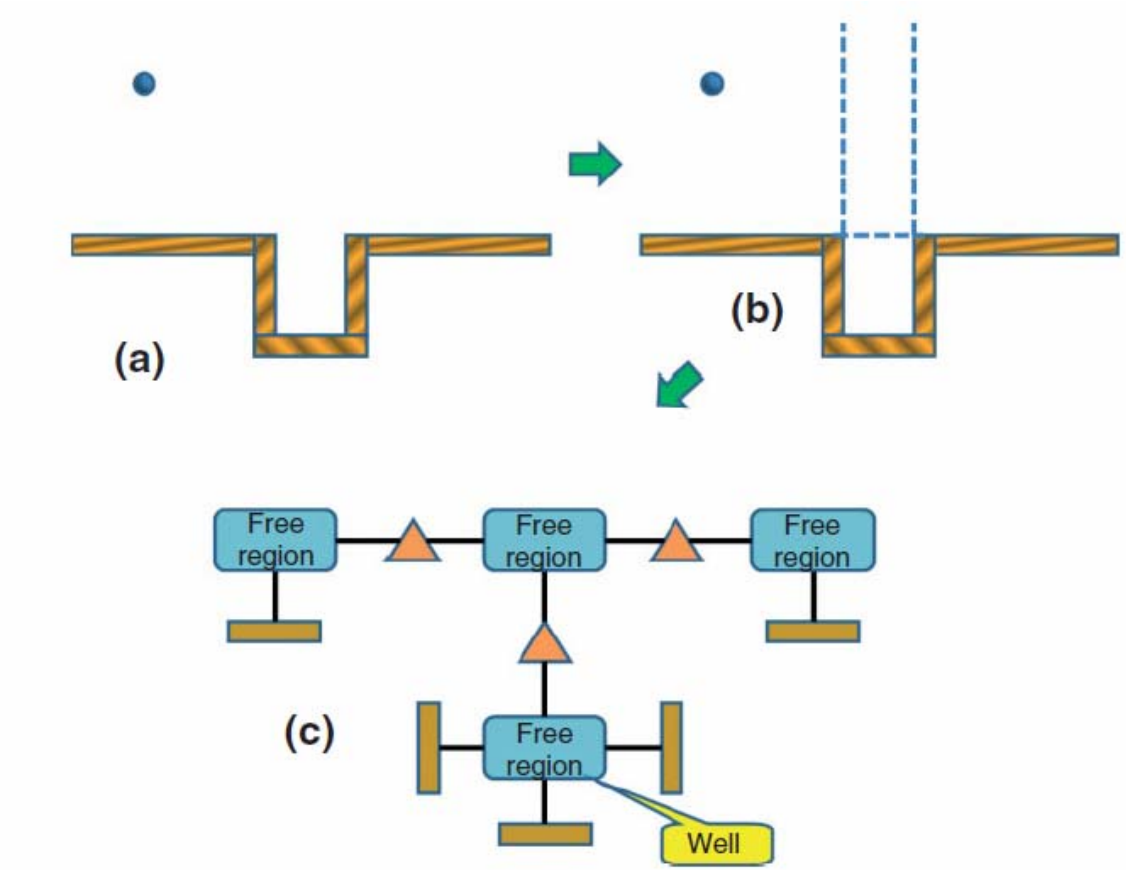
See http://en.wikipedia.org/wiki/Region_connection_calculus

Visual Reasoning

- There are situations when the input is available qualitatively
  - Verbal descriptions
  - Route descriptions
  - Shape descriptions

Visual Reasoning

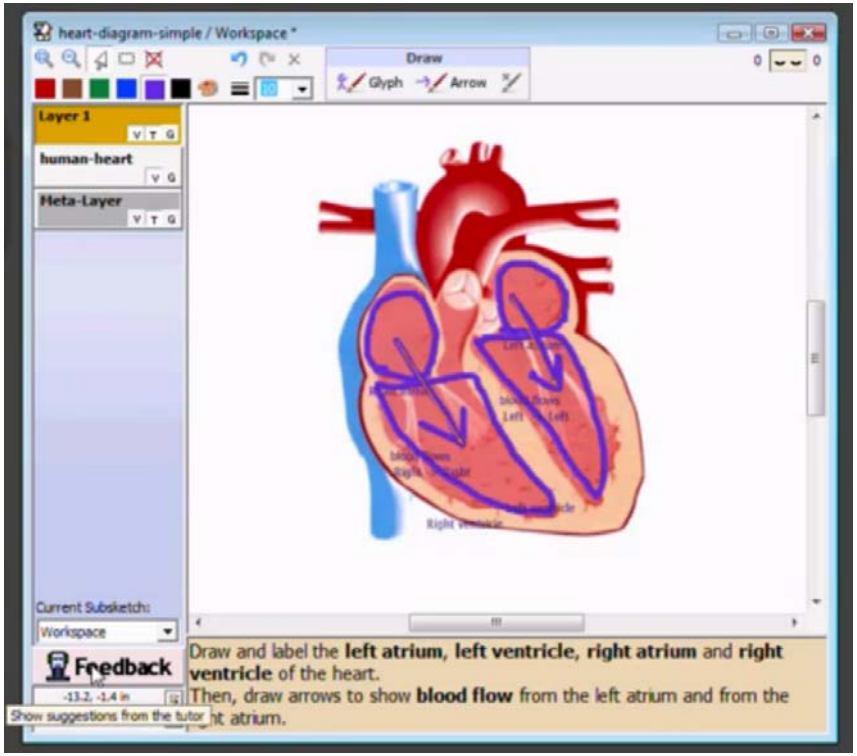
- Place vocabulary



Adapted from Ken Forbus

Visual Reasoning

- See http://www.youtube.com/user/QRGLab#p/u/3/StJH3MJ59Ak



Current Work on Qualitative Reasoning

Past proceedings:
http://www.qrg.northwestern.edu/Resources/qrw_proceedings_index.html

Summary

- Qualitative representation and reasoning provides techniques that aim to model how people understand the continuous aspects of the world
- Formalize everyday notions of causality and provide accounts of how to ground symbolic relational representations in perceptual processes
  - Qualitative processes, spatial relations, visual reasoning
- Numerous applications in education, ecology, diagnosis, engineering

Reading

- Garp 3 --- A Workbench for Qualitative Modeling and Simulation by Bredeweg, Linnebank, Bouwer, Liem