Unit A1.1 Motivation

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Overview

- Why qualitative reasoning?
- Principles of qualitative representation and reasoning
- A brief history of qualitative reasoning

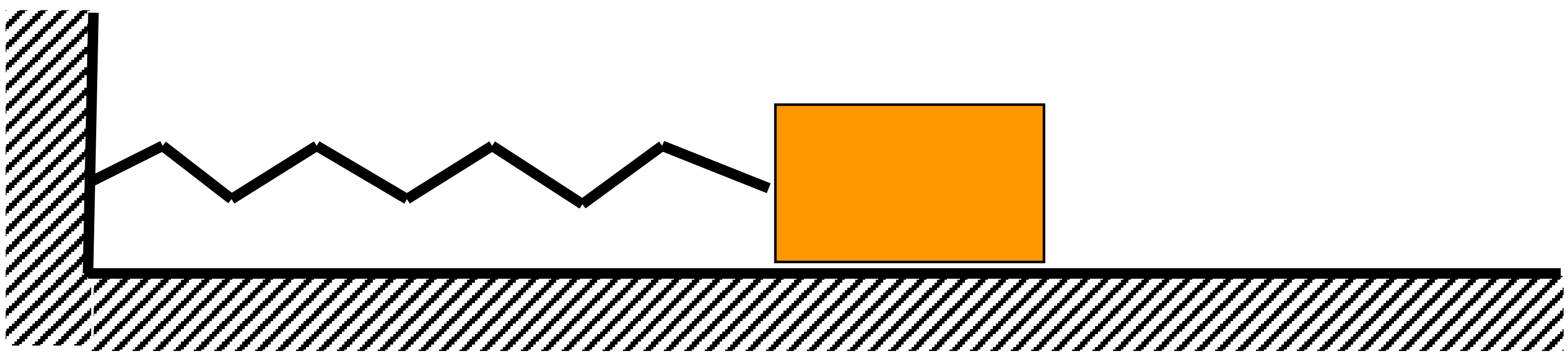
What is qualitative physics?

- Formalizing the intuitive knowledge of the physical world
  - From person on the street to expert scientists and engineers
- Developing reasoning methods that use such knowledge for interesting tasks.
- Developing computational models of human commonsense reasoning

Example

- What happens when you leave an espresso maker on a stove unattended for an hour?

What will this system do?



Example

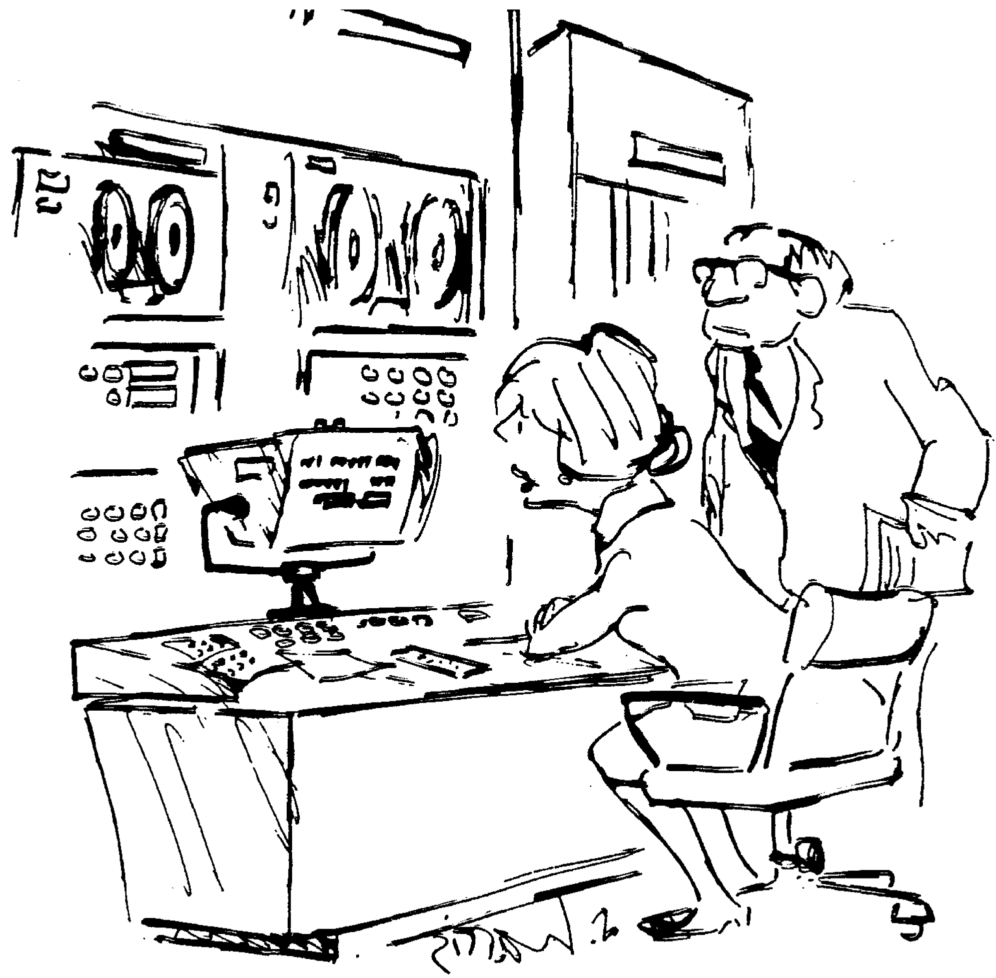
- Why are there seasons?

Example

- Warm water freezes faster in ice cube tray than cold water. Why?

Why do qualitative physics?

- Understanding the mind
  - What do people know? Physical, social, and mental worlds.
  - Universal, but with broad ranges of expertise
    - Unlike vision, which is automatic
    - Unlike medical diagnosis

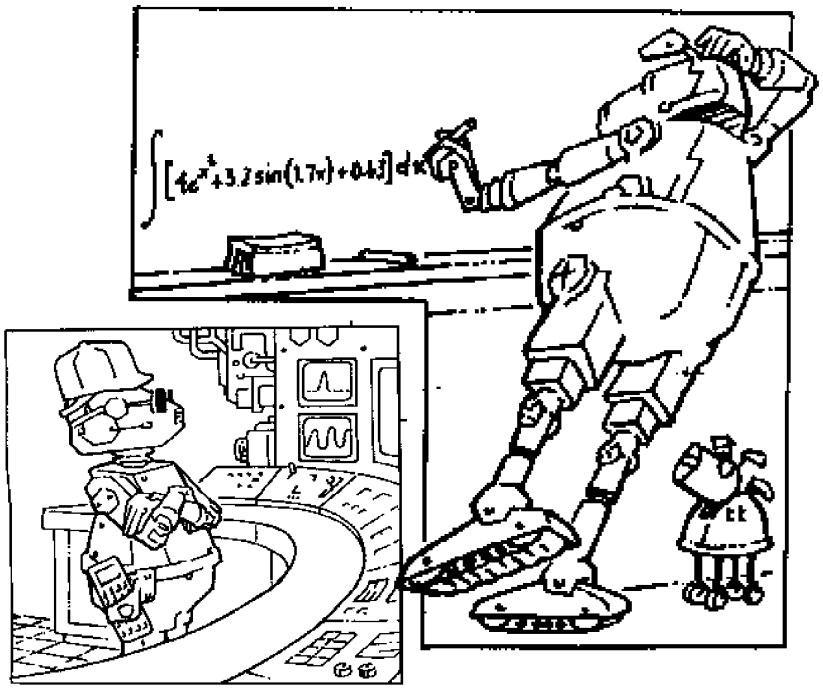


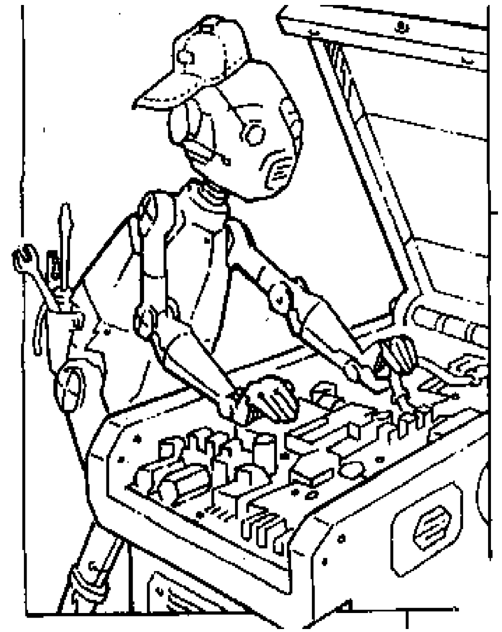
“It says it’s sick of doing things like inventories and payrolls, and it wants to make some breakthroughs in astrophysics

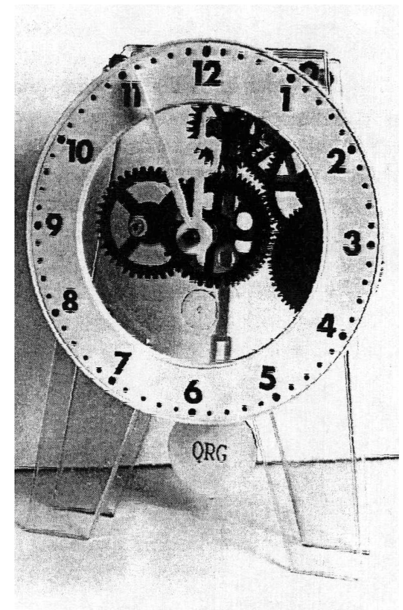
Why do qualitative physics?

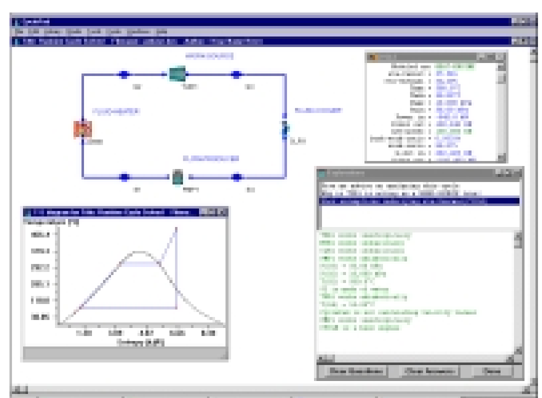
- Can build useful software and systems
  - Intelligent tutoring systems and learning environments
  - Engineering Problem Solving
    - Diagnosis/Troubleshooting
    - Monitoring
    - Design
    - Failure Modes and Effects Analysis (FMEA)
  - Robots
  - Models for understanding analogies and metaphors
    - “Ricki blew up at Lucy”

Engineering applications have driven most Qualitative/Model-based reasoning research

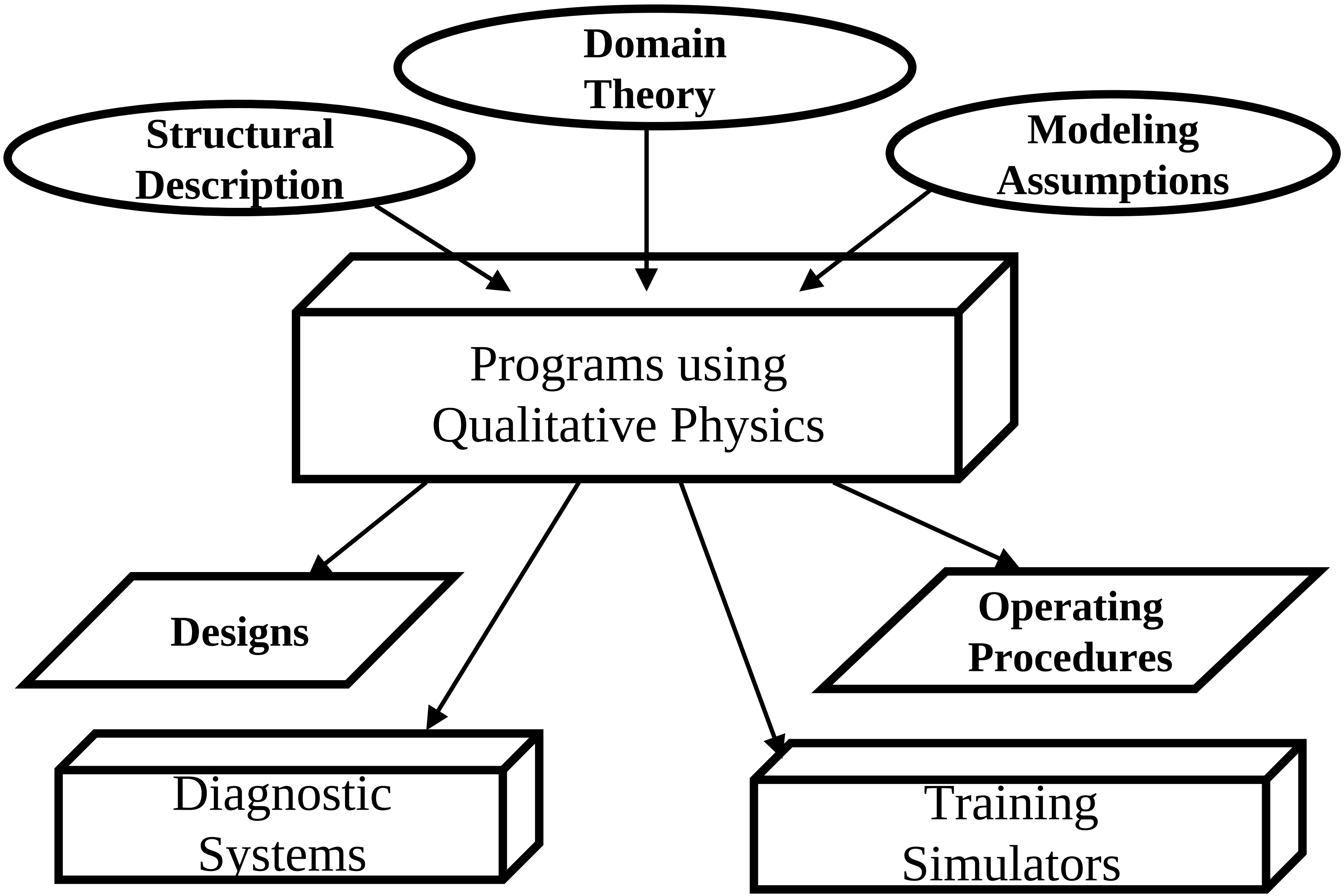




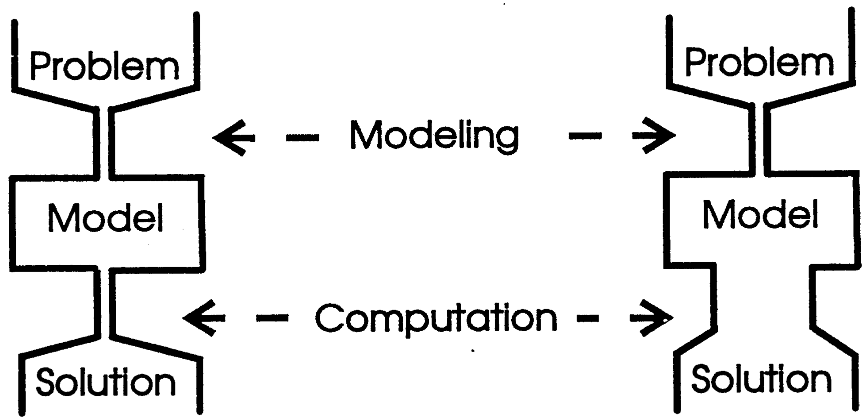




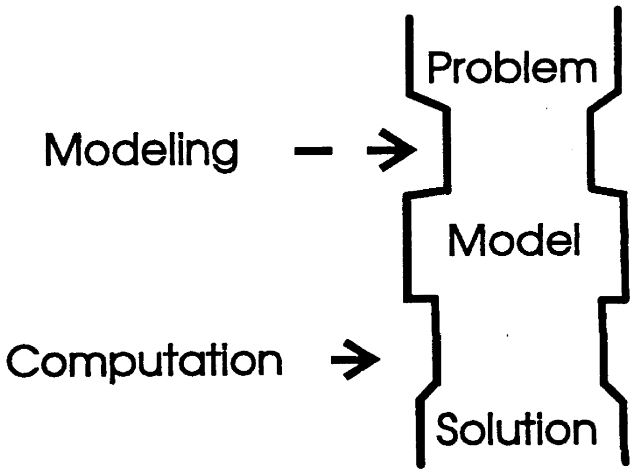
The Qualitative Physics Vision



Effect of Digital Computing on Engineering Problem Solving



Desired effect of Qualitative Physics on Engineering Problem Solving



Key Ideas of Qualitative Physics

- Quantize the continuous for symbolic reasoning
  - Example: Represent numbers via signs or ordinal relationships
  - Example: Divide space up into meaningful regions
- Represent partial knowledge about the world
  - Example: Is the melting temperature of aluminum higher than the temperature of an electric stove?
  - Example: “We’re on Rt 66” versus “We’re at Exit 42 on Rt 66”
- Reason with partial knowledge about the world
  - Example: Pulling the kettle off before all the water boils away will prevent it from melting.
  - Example: “We just passed Exit 42, and before that was 41. We should see 43 soon.”

Comparing qualitative and traditional mathematics

- Traditional math provides detailed answers
  - Often more detailed than needed
  - Imposes unrealistic input requirements
- Qualitative math provides natural level of detail
  - Allows for partial knowledge
  - Expresses intuition of causality

$$\mathbf{F = MA}$$

Traditional quantitative version

$$\mathbf{A \propto_{Q+} F}$$

$$\mathbf{A \propto_{Q-} M}$$

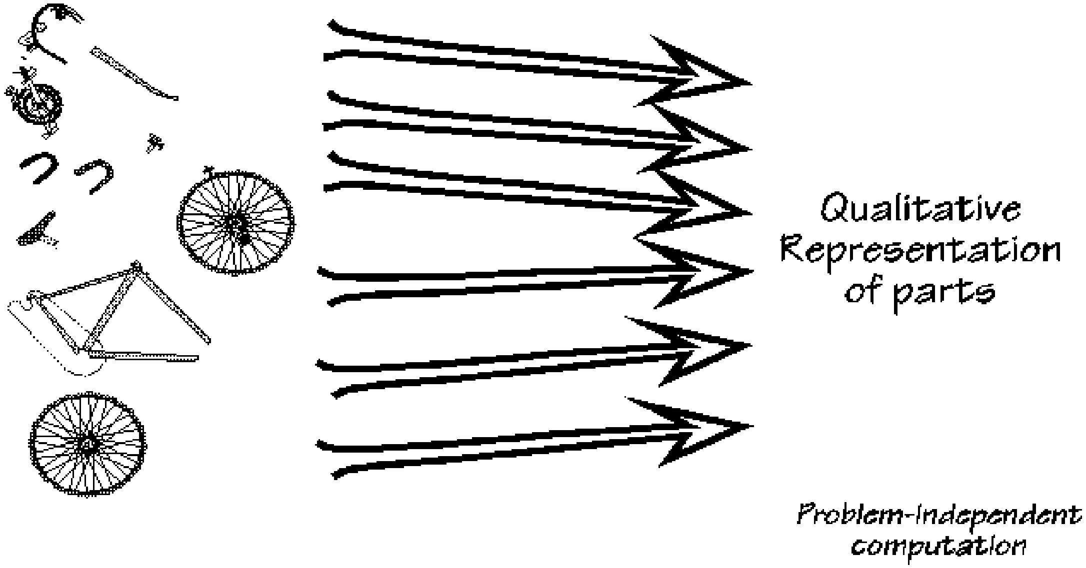
Qualitative version

Qualitative Spatial Reasoning

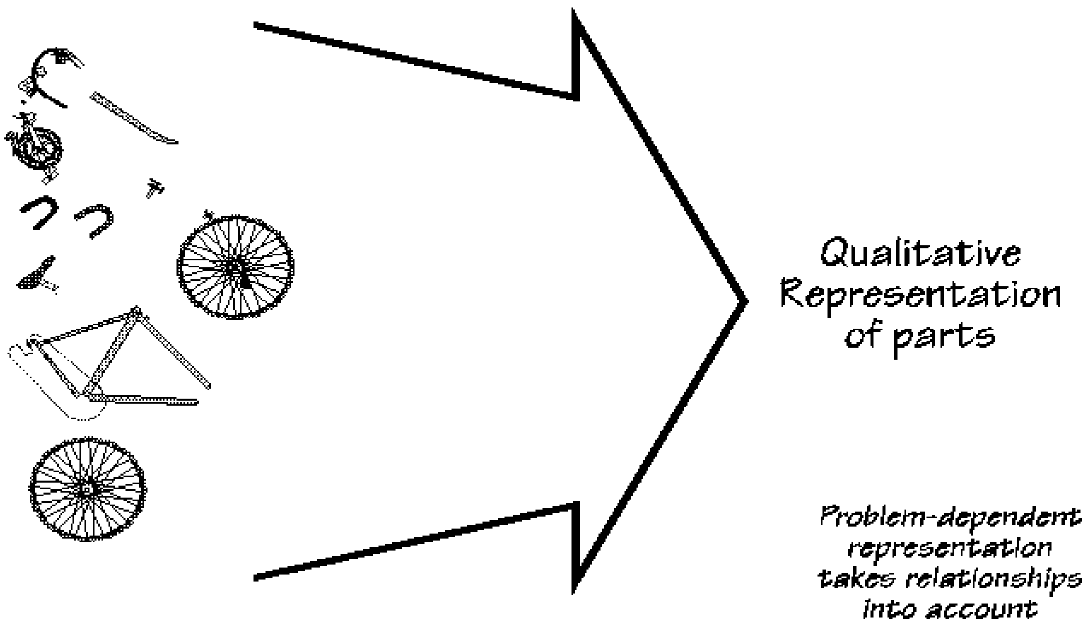
- Claim: Symbolic vocabularies of shape and space are central to human visual thinking
  - They are computed by our visual system
  - Their organization reflects task-specific conceptual distinctions as well as visual distinctions
  - They provide the bridge between conceptual and visual representations

Poverty Conjecture

- There is no purely qualitative, general-purpose representation of spatial properties
- Arguments for it
  - Pervasive human use of diagrams & model
  - Nobody’s done it
  - Mathematics: No notion of partial order in dimensions greater than 1.
  - Examples of specific tasks
- Prediction: People map spatial problems to 1D subspaces as much as possible



Can’t compute qualitative spatial descriptions in isolation



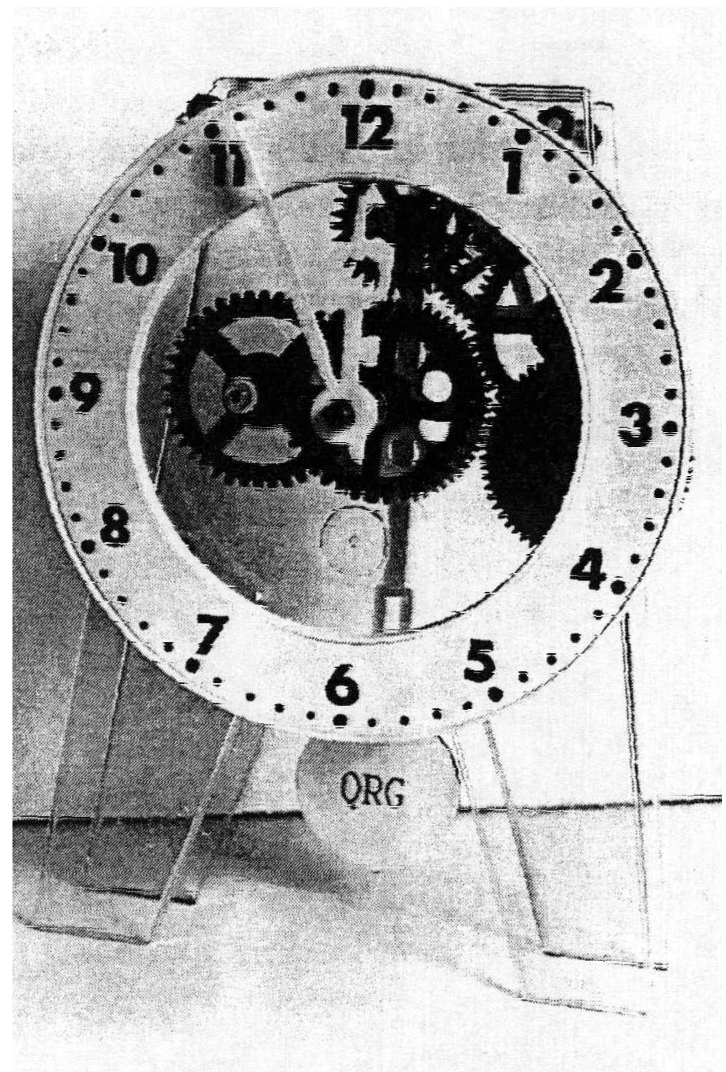
Can compute qualitative spatial descriptions for a given task and context, using visual reasoning

Arguments against Poverty Conjecture

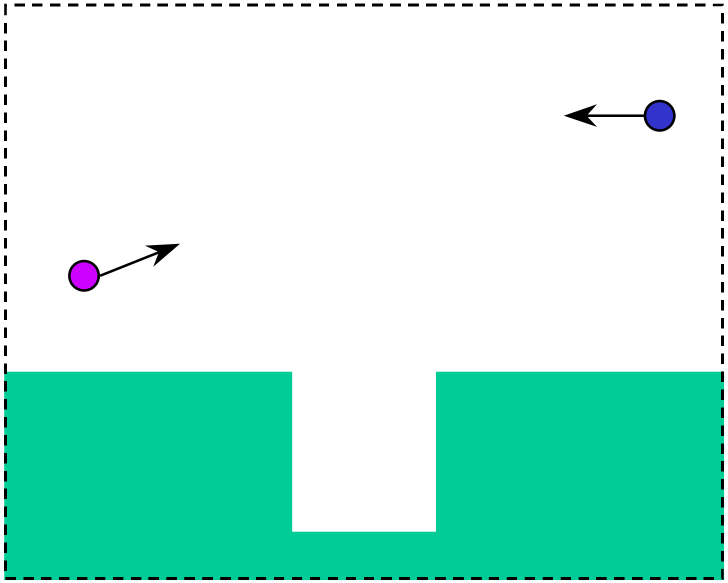
- For some types of qualitative spatial reasoning, topological representations suffice (e.g., Cohn)
- Some spatial tasks can be done by purely qualitative representations, but others can't.
- Open questions:
  - What kinds of information are sufficient for which tasks?
  - What kinds of information do people actually use in those tasks?

Metric Diagram/Place Vocabulary model

- Qualitative representations express natural level of human knowledge & reasoning
- *Metric Diagram/Place Vocabulary* model links diagrammatic reasoning to conceptual knowledge
- Metric Diagram ≈ Visual Routines Processor
- Place Vocabulary ≈ Problem-specific qualitative representation



Example: Reasoning about motion of a ball (FROB)

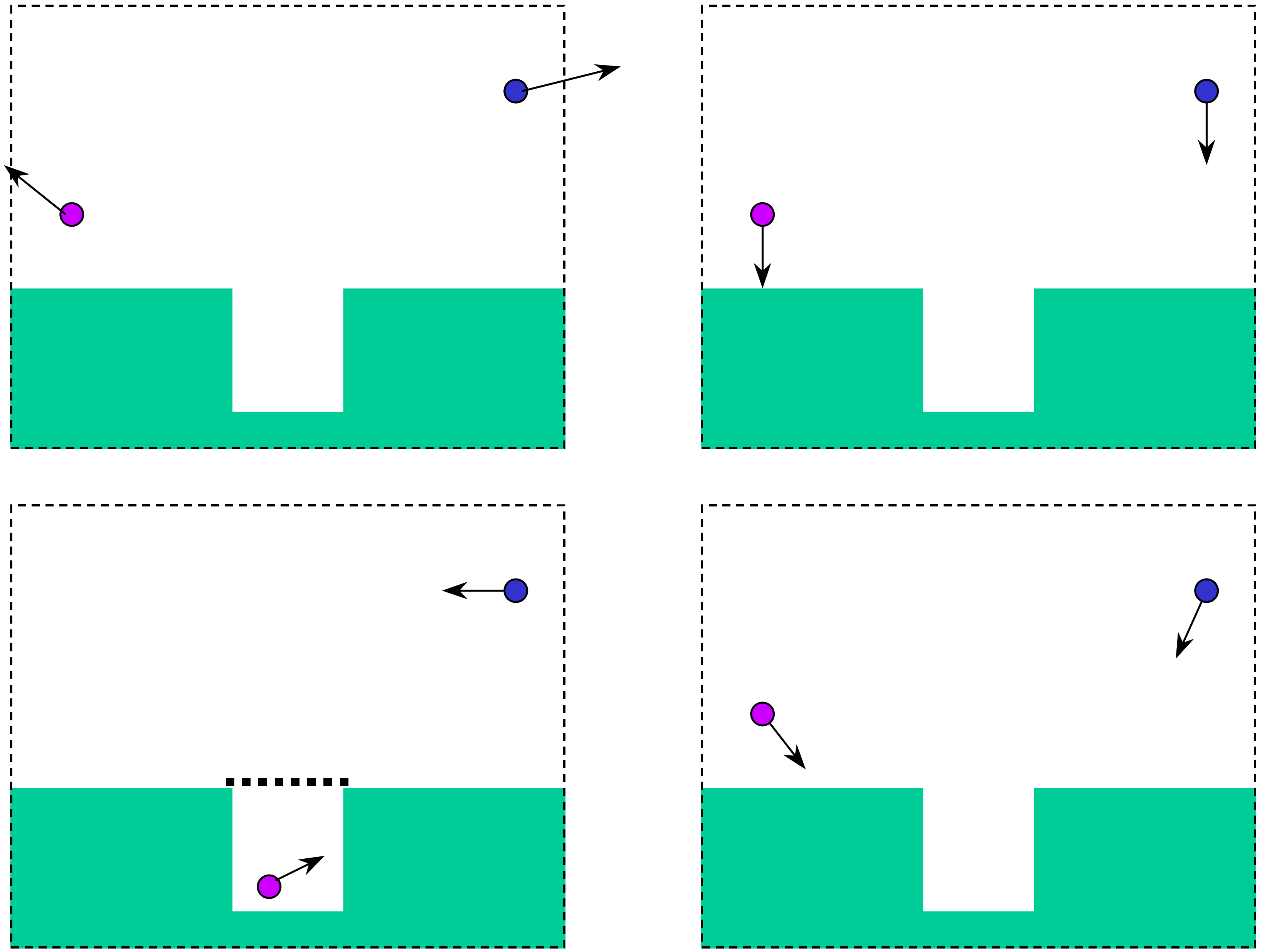


Q: Where can it go?

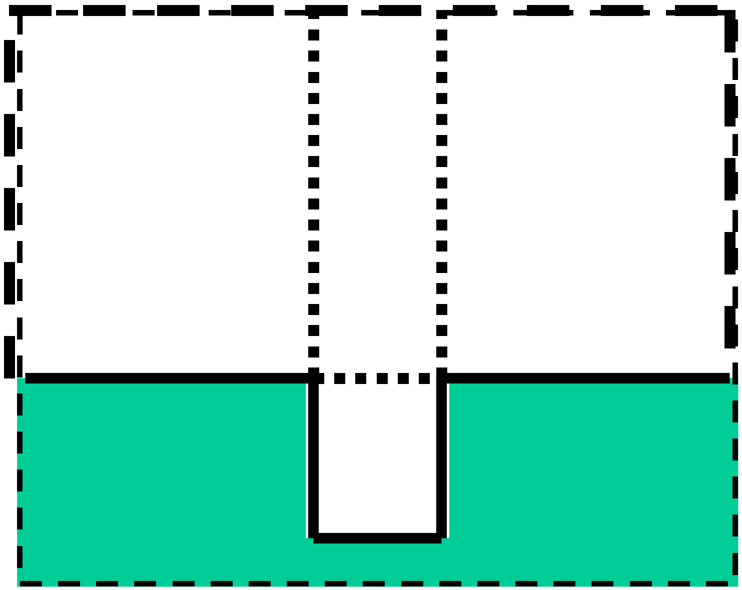
Q: Where can it end up?

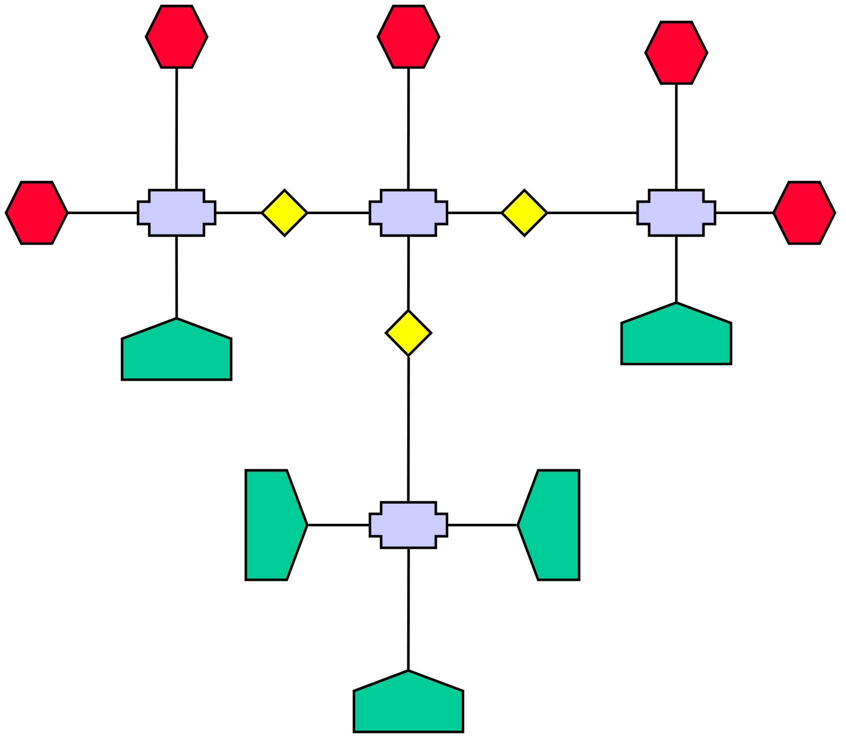
Q: Can A and B collide?

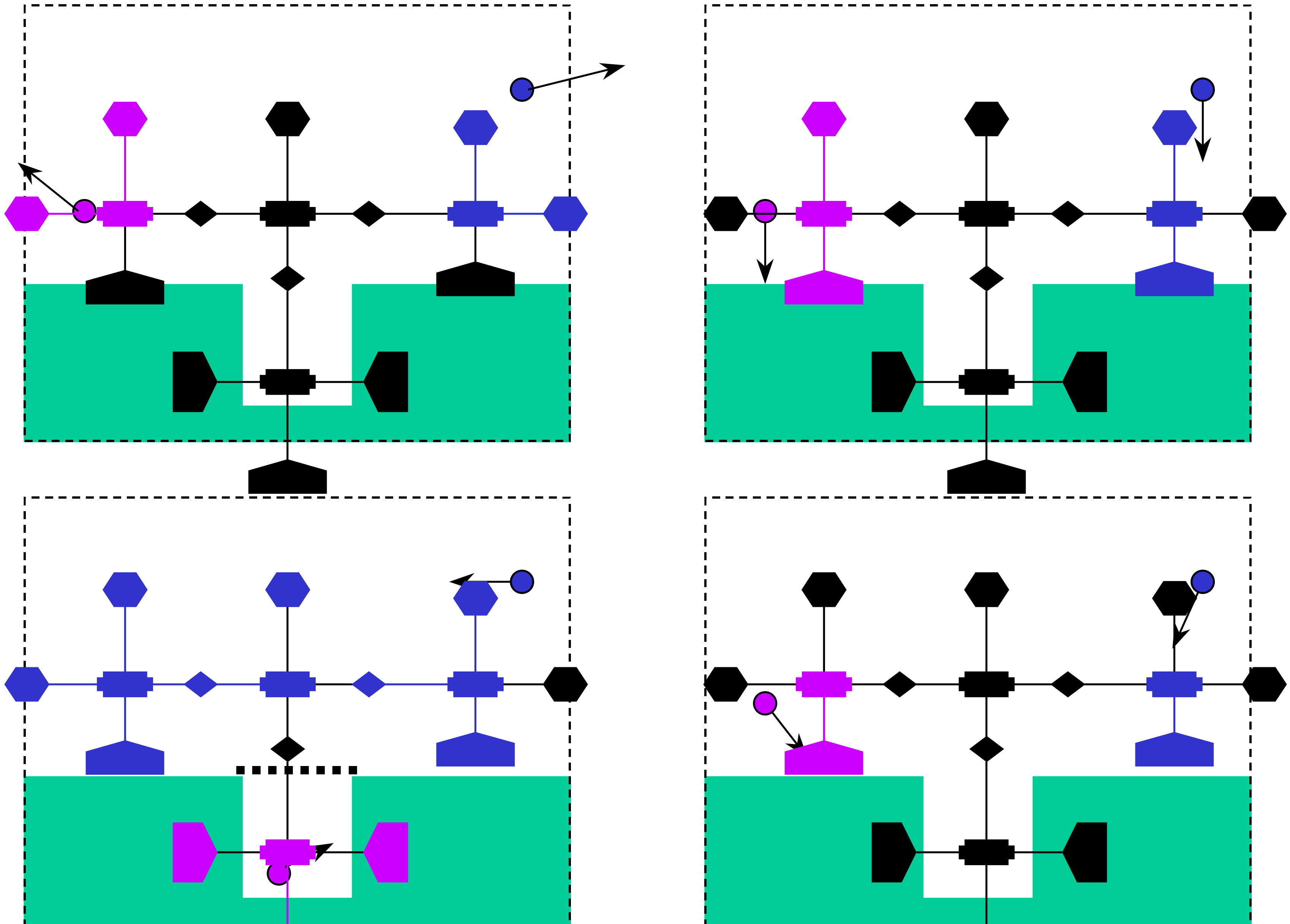
A is purple, B is blue



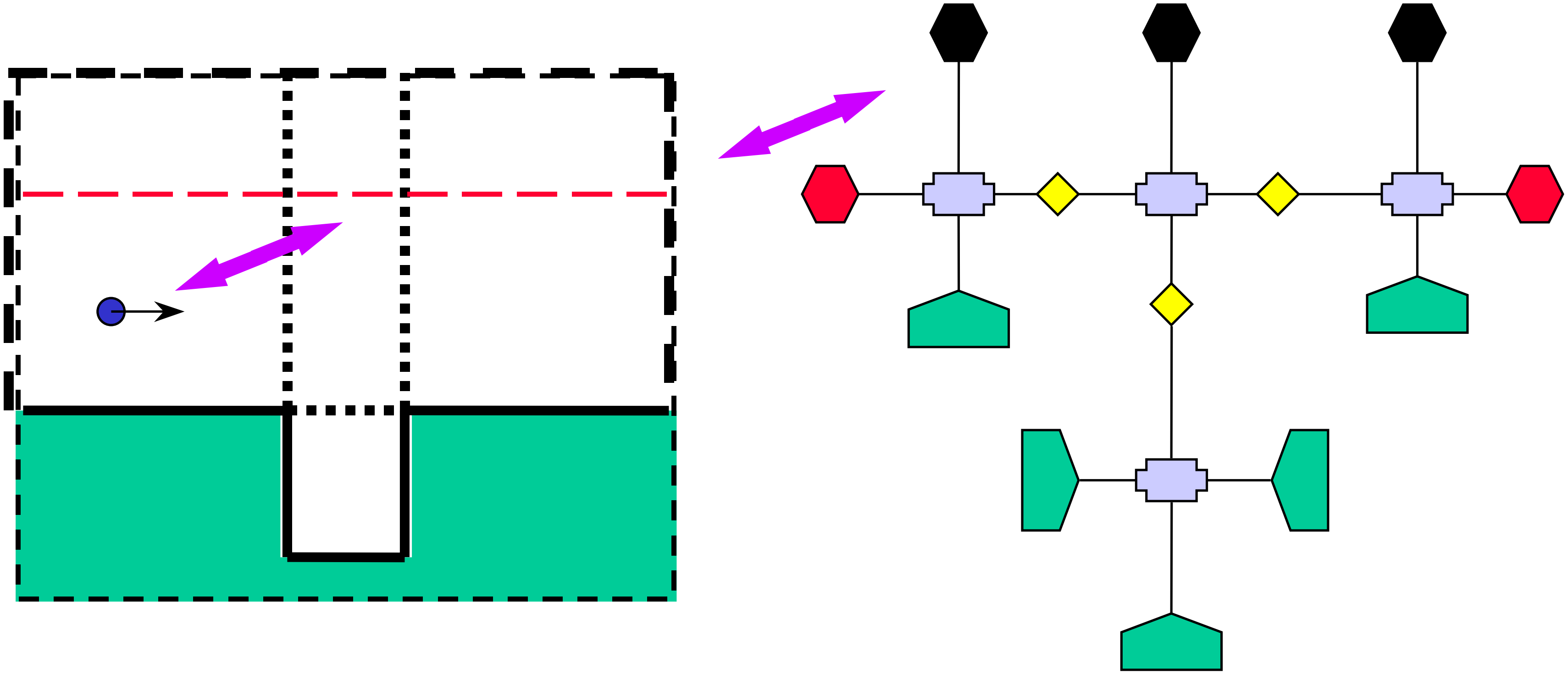
Creating a place vocabulary for a FROB world







Integrating qualitative and metric knowledge



A brief history of qualitative reasoning

- Prehistory
- Initial steps
- Rise of general theories (1981-1984)
- Rapid expansion (1985-1991)
- Maturity (1992-1999)
- New directions (2000-????)

Prehistory

- Charniak
  - Common sense needed to solve story problems
- Rieger
  - Simple cause/effect mechanism descriptions
- Simple fixed-symbol vocabularies
  - TALL, MEDIUM, SMALL
  - Fuzzy logic

Initial steps (1975-1980)

- NEWTON (de Kleer, 1975)
  - Identified importance of qualitative reasoning in problem solving
  - Introduced notion of envisionment
- Naïve Physics Manifesto (Hayes, 1978)
  - Widely circulated, very inspirational
  - Introduced notion of histories
- FROB (Forbus, 1980)
  - Metric Diagram/Place Vocabulary model

Rise of general theories (1981-1984)

- Confluences (de Kleer and Brown)
  - Articulated notion of *mythical causality*
  - Clean sign-based qualitative calculus
- ENV → QSIM (Kuipers)
  - Articulated importance of qualitative mathematics
  - Introduced *landmark values* to encode richer behavioral distinctions
- Qualitative Process theory (Forbus)
  - Articulated notion of *physical processes* as causal mechanisms
  - Introduced ordinal relations as qualitative values

Rapid expansion (1985-1991)

- General Diagnostic Engine (Williams and de Kleer)
- Explorations of qualitative reasoning
  - Chatter and how to get rid of it (legions)
  - Qualitative reasoning about phase space (Yip, Nishida)
  - Order of magnitude representations
- First applications
  - Qualitative Process Automation (LeClair & Abrams)
  - MITA photocopier (Tomiyama et al)

Maturity (1992-1999)

- More applications work
  - Lots of interesting demonstrations
  - More fielded applications
- Many new ideas, old ideas pushed farther
  - Order of magnitude representations
  - Reasoning about chaos and nonlinear dynamics via qualitative phase space descriptions
  - Model construction from data in material science, medicine
  - Compositional modeling
  - Self-explanatory simulators
  - Teleological reasoning
  - Large-scale textbook problem solving

New directions (2000 and beyond)

- Deeper ties to engineering
- Deeper ties to science
  - Material Science (cf Ironi)
  - Cognitive Science (cf Bredeweg & deKonig, Forbus & Gentner)
  - Biology (cf Trelease & Park)
- And whatever other new directions *<u>you</u>* come up with!
  - Several factors are radically changing our world
    - Moore’s law
    - Rise of the networked world