A Multi-Agent Framework for General Purpose Situational Simulations in Construction Management

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Outline

- Motivation and background
- Overview of proposed system
- Agents and agent frameworks
- The Interface
- Experimentation and Verification
- Work completed and the road ahead
- Deliverables
- Potential contributions
- Limitations of research

Construction Education

Curriculum only teaches theory and students may encounter difficulties in applying the theory to real life problems

-- McCabe et. al., 2000

The current curriculum does not take into account the significance of hands-on experience / interaction with practitioners

-- Sawhney et. al., 2001

Construction Education

- Construction domain is multifaceted
  - Cost and Schedule control
  - Planning for unforeseen events
  - Crisis management: ‘What if’ scenarios
- Fragmented nature of coursework insufficient

Problem Statement - I

How do we bridge the disconnect between learner and learning environment in construction education ?

↓

Traditional efforts beyond classroom environments . . .

↓

Simulations

Authentic Learning

What it is not . . . → A mapping of external events to internal symbols
- Maturana et. al. 1989

What it may be . . . → Greater contextualized understanding of the experiential world
- Constructivism

Cognitive activity is contextually situated
- Brown et.al. 1987

Virtual Gorilla Project (Allison et.al. 1997),
Virtual Puget Sound (Windschitl et.al. 2000)

Suggested Solution - I

Disconnect between learner and learning environment in construction education

Traditional efforts beyond classroom environments

Simulations

Situated Cognition

Situational Simulations

Simulations

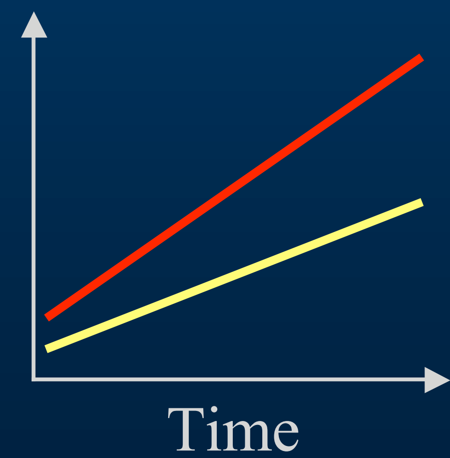
Initial State

t_0

Projected Final State

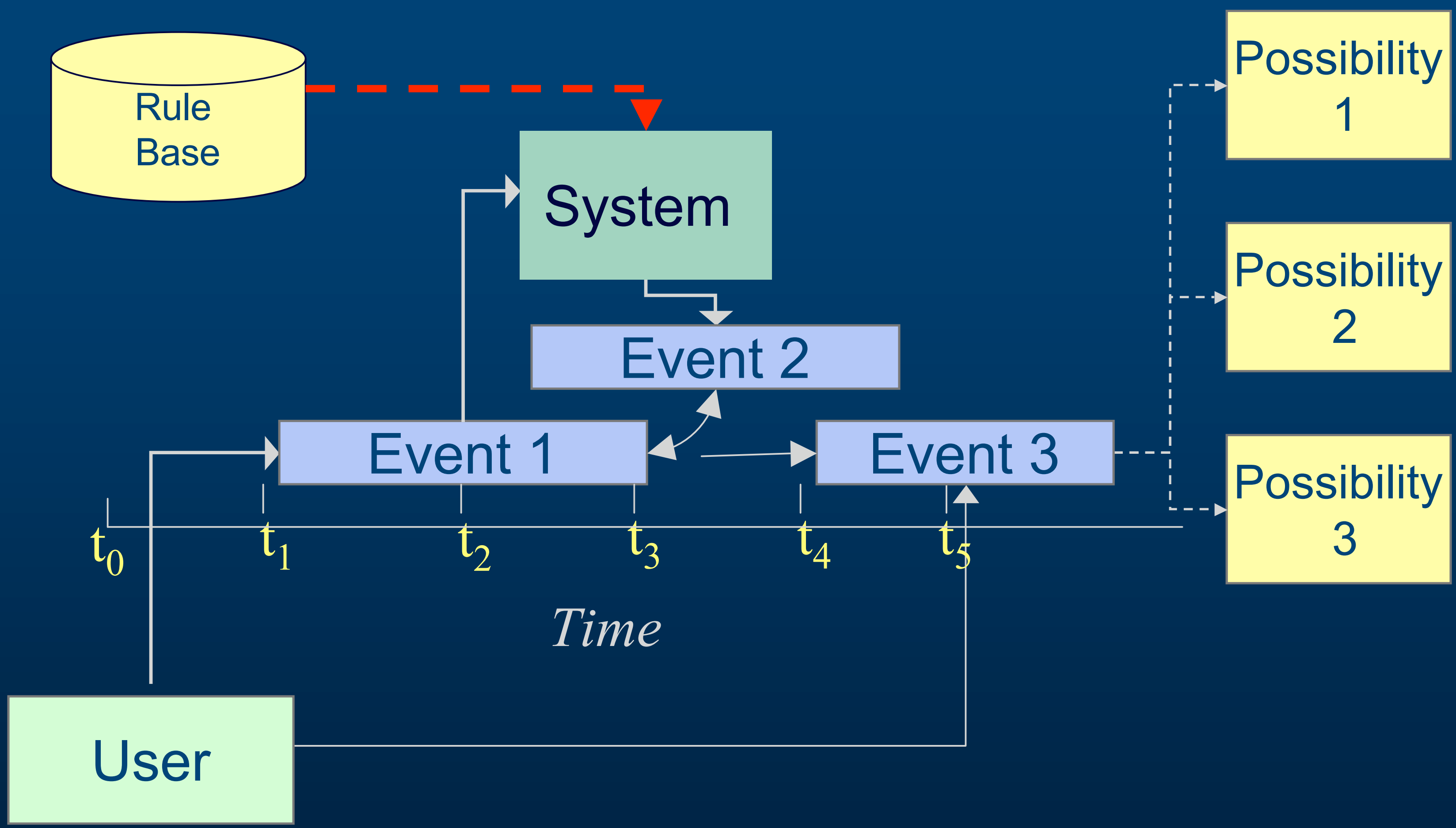
t_{++}

Defined Growth Functions/ Domain Model



Example: (Martinez, 2001)
** Model input parameters **
Amount of soil in m3: --
Truck cost ($/hr): --
…
** Calc results after sim. **
Production rate (m3/hr): --
Unit cost ($/m3) --
Averages over runs: ---

Situational Simulations



Construction Simulations

Construction Management Processes (CMP)

Processes that construction managers encounter in decision making:

-Activity, Space and Resource Scheduling

-Cost Control

-Design Reviews and Change Orders

Construction Operations (CO)

Specific construction operations:

-Earth Moving

-Concrete Pouring

-Tunneling

Construction Simulations

Special Purpose
-Restricted scope
-Problem specific
-Simulation models are not reusable

General Purpose
-Flexible scope
-Programmable environment
-Allows collaboration and promotes new simulations amongst developers

	Special Purpose	General Purpose
CMP	CONSTRUCTO - Halpin (1973) CEPM Game -Veshosky et. al. (1991) SuperBid - AbouRizk (1993) STRATEGY - McCabe et. al. (2000)	
CO	Simphony -AbouRizk (1993) EZSTROBE -Martinez (2001)	CYCLONE - Halpin (1973) STROBOSCOPE -Martinez et. al. (1999)

Claim - I

A general purpose situational simulation environment for the construction management domain is needed . . .

Simulation Paradigms

- Activity Scanning (AS)
  - Use of Activity Cycle Diagrams (ACD)
  - CYCLONE (Halpin, 1973), STROBOSCOPE (Martinez et. al., 1999)
- Process Interaction
  - Use of network models and flow diagrams
  - SLAM-II
- Event Scheduling
  - Use of event graphs
  - SIGMA

Activity Cycle Diagrams

- Set of Activities: each activity associated with
  - A set of conditions
  - A predetermined outcome
- Activities occur in sequence

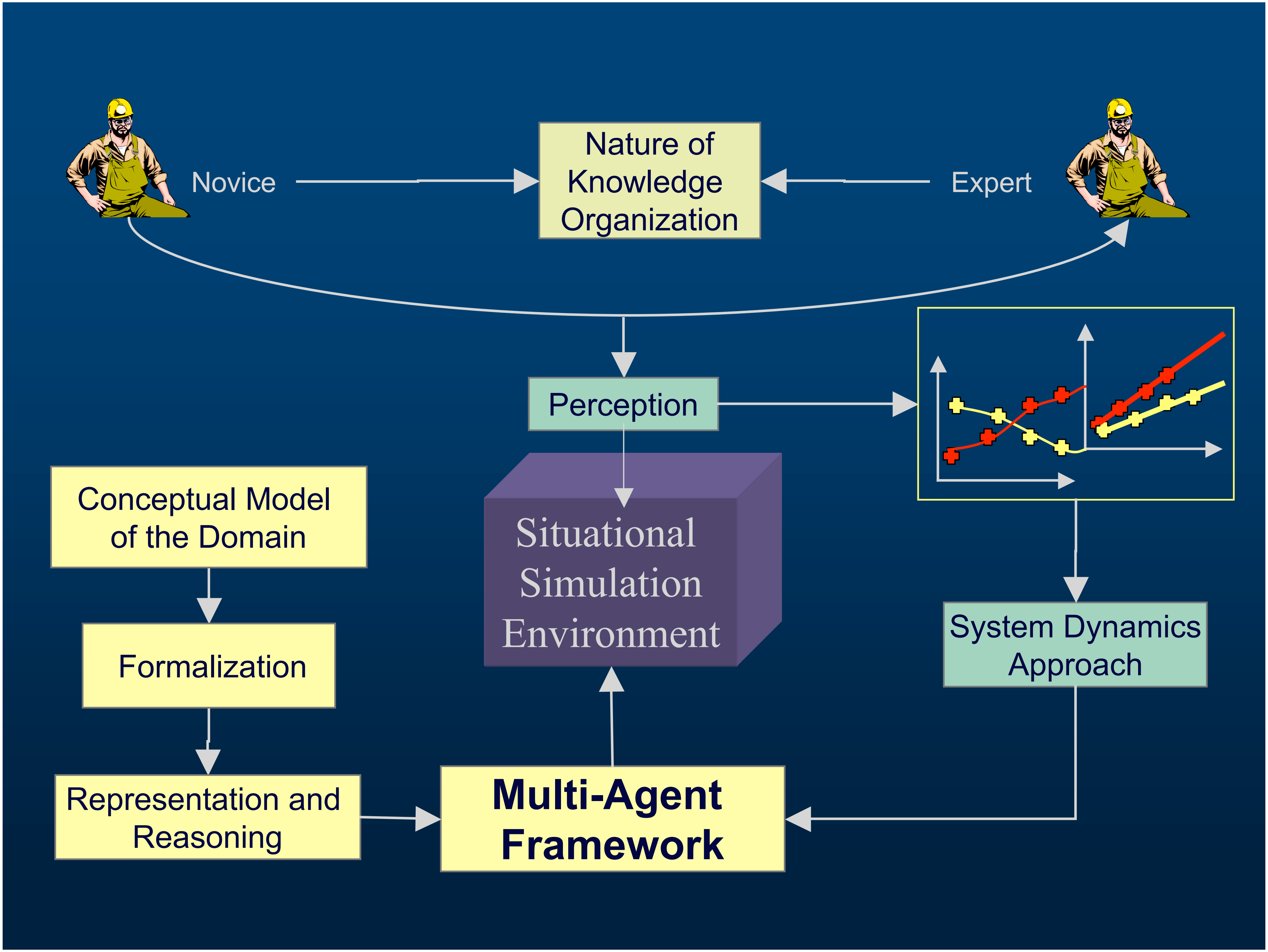
Problem Statement - II
Need for a new paradigm

- Interactive
  - Simulation and participant: a coupled system
- Able to express:
  - Parallel overlapping events
  - Instantaneous/Time consuming actions and events

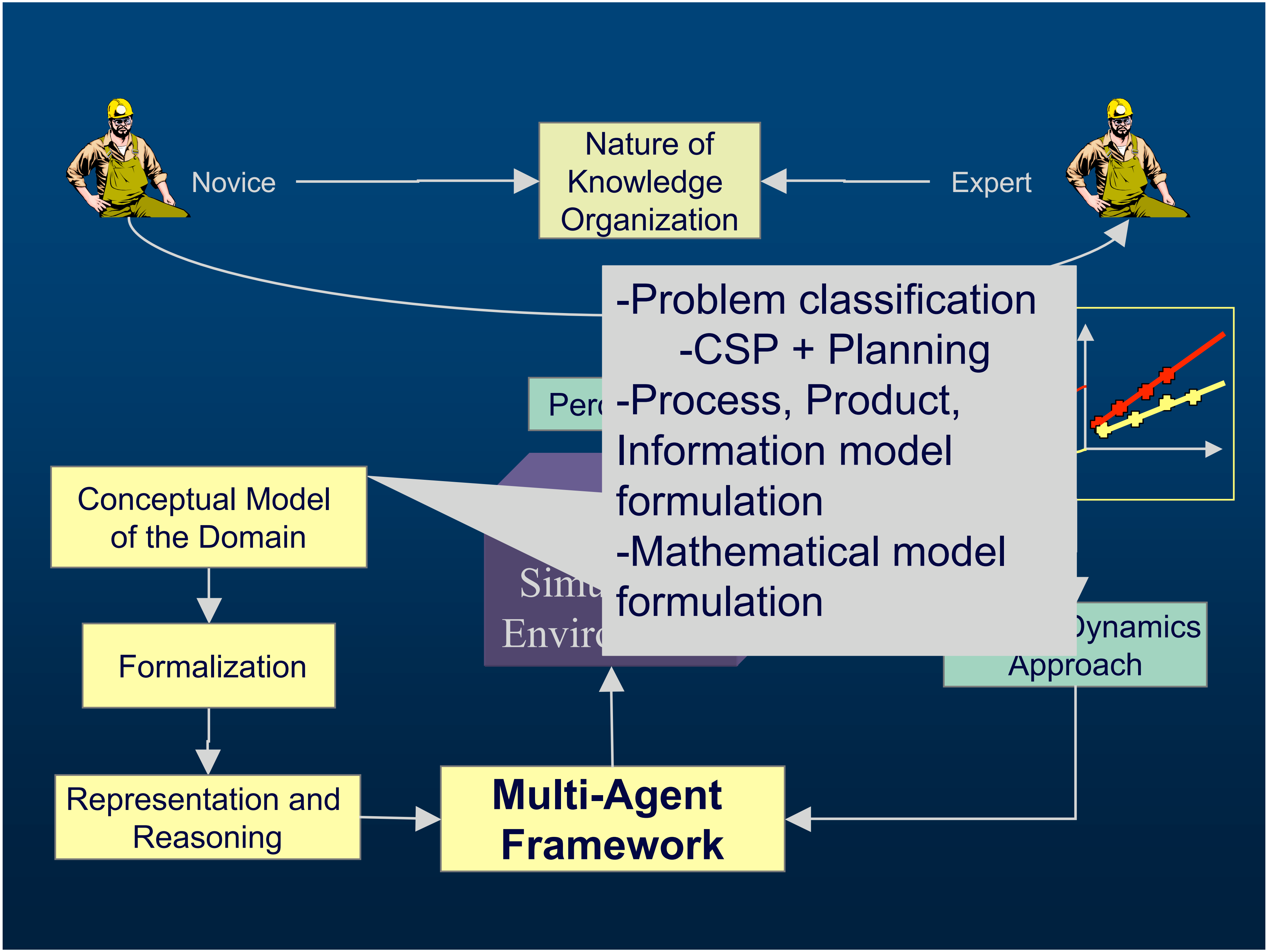
Suggested: A Multi-Agent approach

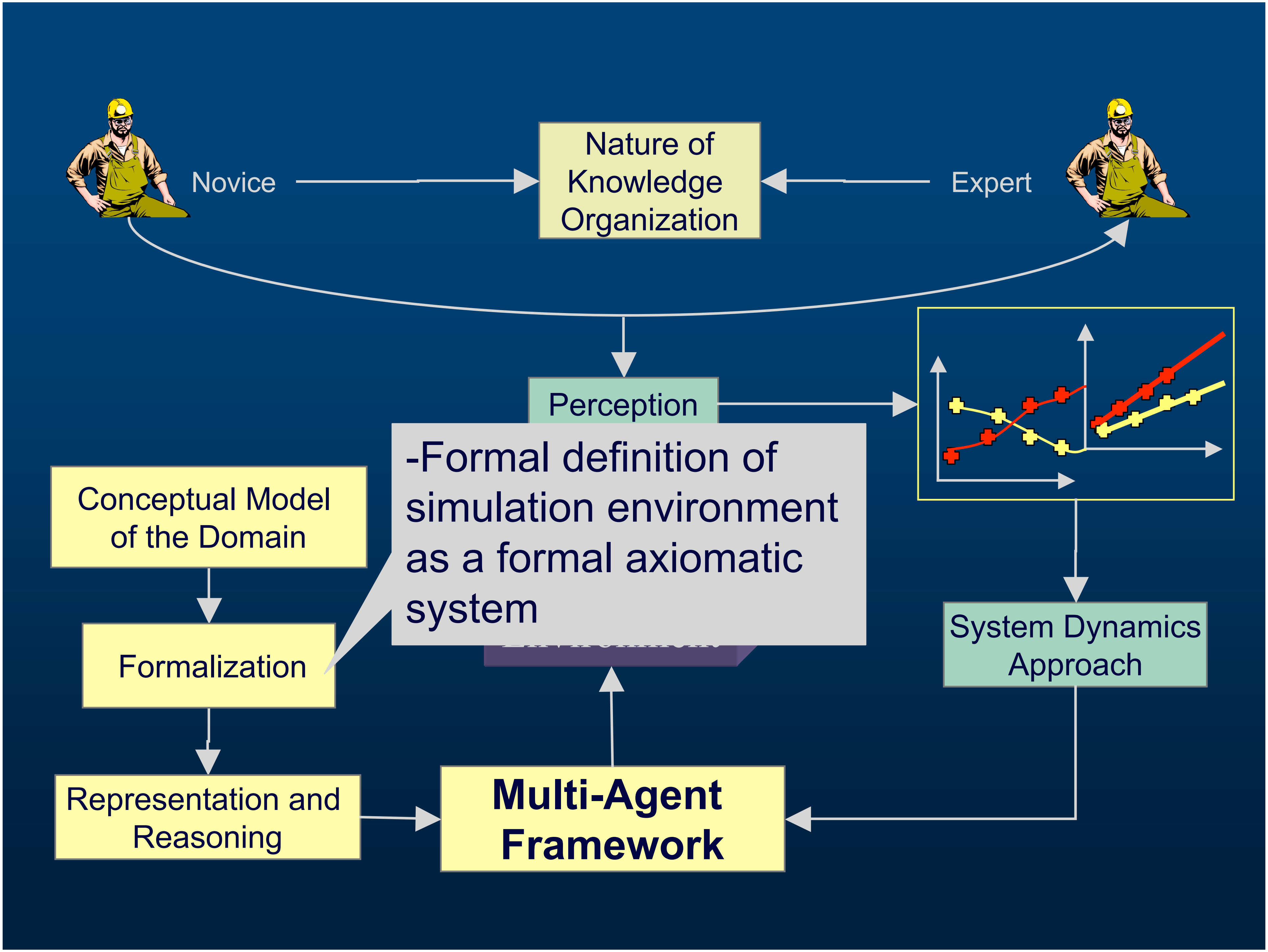
Claim

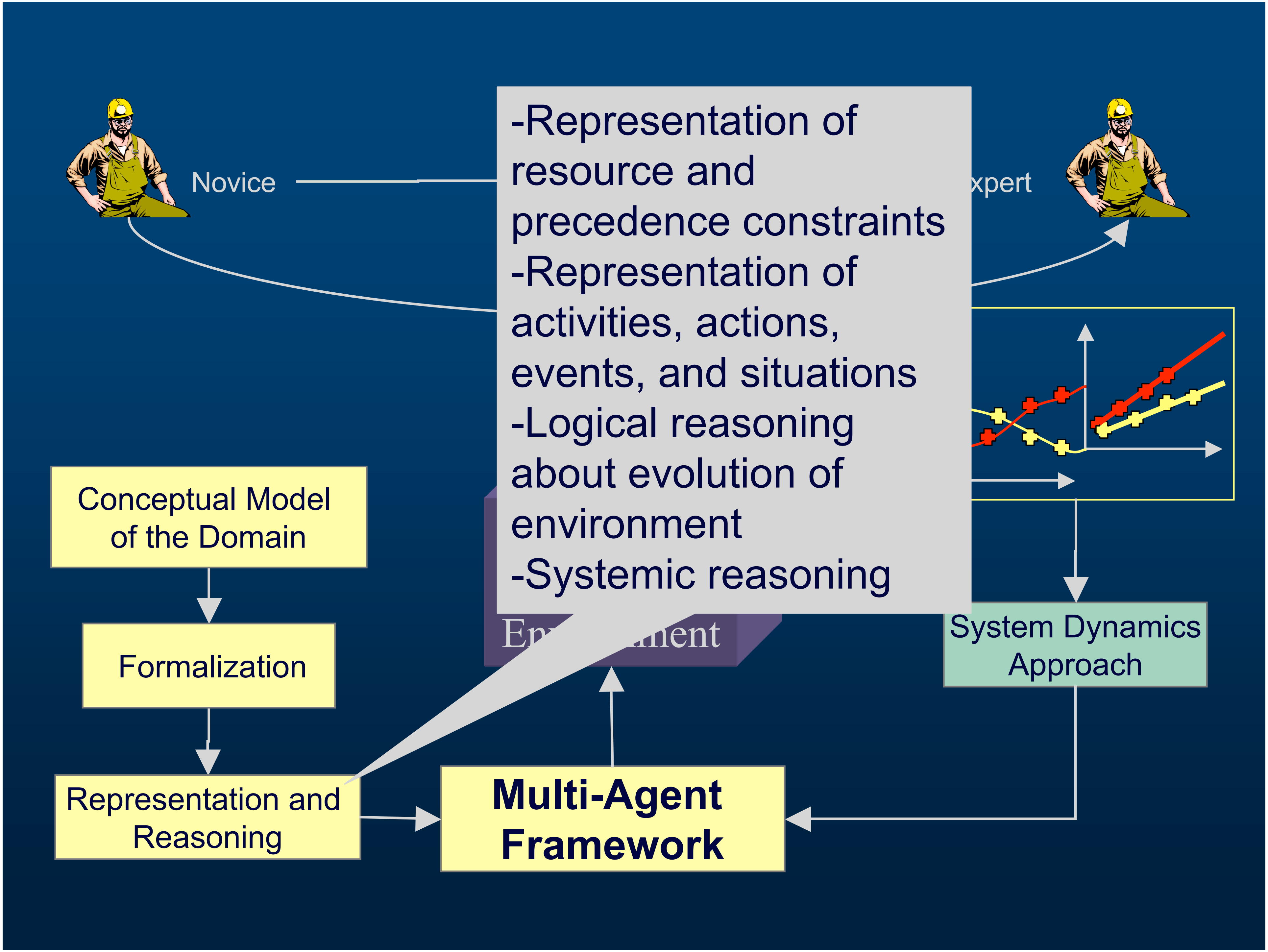
A general purpose situational simulation environment for the construction management domain can be created using a multi-agent framework.

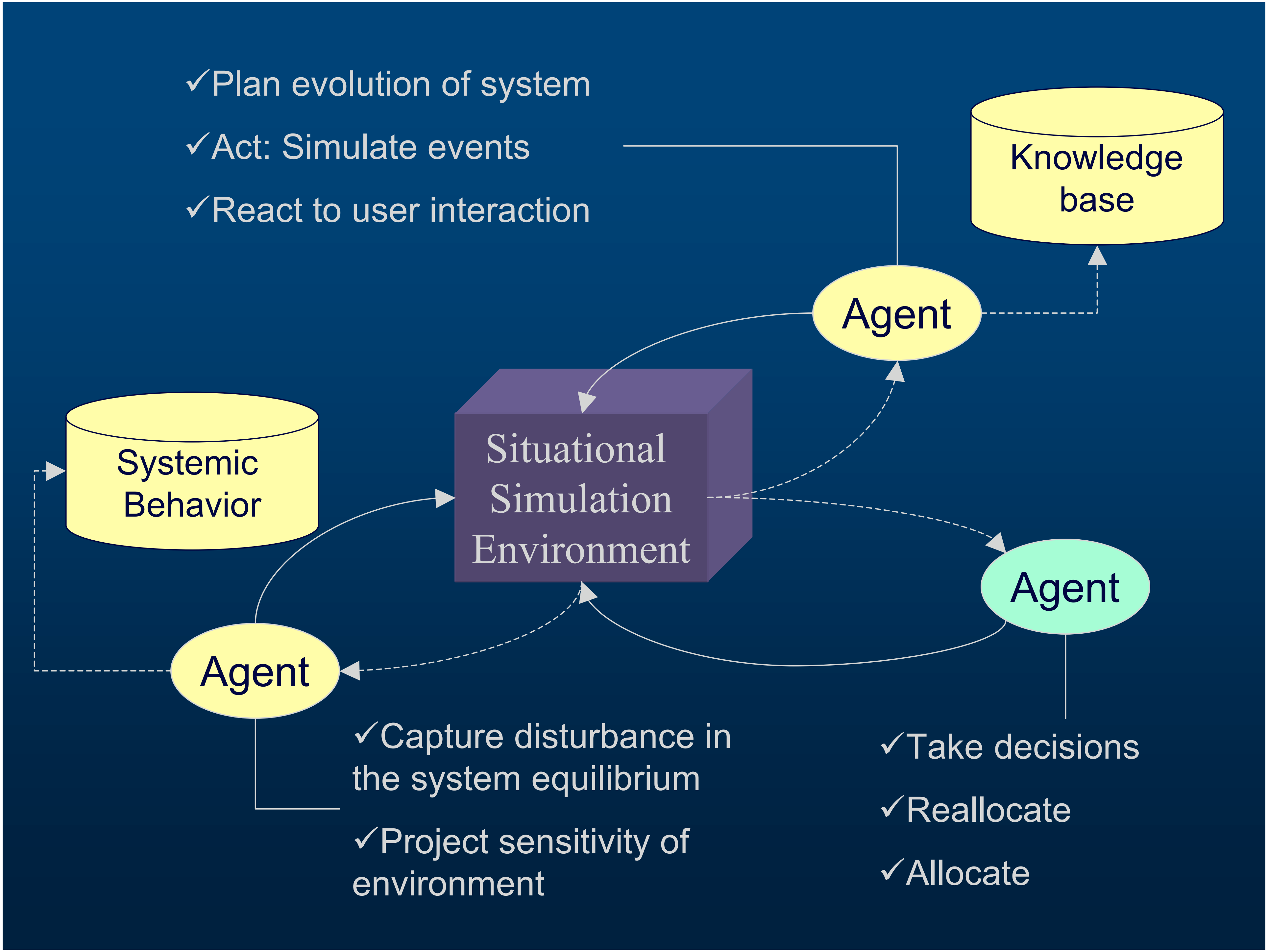


Novice
Nature of Knowledge Organization
Expert
Perception
Situational Simulation Environment
Conceptual Model of the Domain
Formalization
Representation and Reasoning
Multi-Agent Framework
System Dynamics Approach


Novice
Nature of Knowledge Organization
Expert
-Problem classification
-CSP + Planning
-Process, Product, Information model formulation
-Mathematical model formulation
Perc
Conceptual Model of the Domain
Formalization
Representation and Reasoning
Simu
Envir
ynamics Approach
Multi-Agent Framework


Novice
Nature of Knowledge Organization
Expert
Perception
Conceptual Model of the Domain
Formalization
-Formal definition of simulation environment as a formal axiomatic system
System Dynamics Approach
Representation and Reasoning
Multi-Agent Framework


-Representation of resource and precedence constraints
-Representation of activities, actions, events, and situations
-Logical reasoning about evolution of environment
-Systemic reasoning
Novice
xpert
Conceptual Model of the Domain
Formalization
Representation and Reasoning
Multi-Agent Framework
System Dynamics Approach



✓Plan evolution of system
✓Act: Simulate events
✓React to user interaction
Knowledge base
Agent
Systemic Behavior
Situational Simulation Environment
Agent
Agent
✓Capture disturbance in the system equilibrium
✓Project sensitivity of environment
✓Take decisions
✓Reallocate
✓Allocate

Agent Properties

- Perceptive to the environment
- Capable of logical reasoning
- Capable of autonomous action
  - Information attitudes
  - Pro attitudes
- Acts in a goal oriented fashion
- Dynamically integrates experiences

Agent Environments

- Software environments (Etzioni 1993)
  - Static planning in limited information worlds
- Robotic environments (Brooks 1991)
  - Low level motor control and perception
- Test-bed environments (Hanks et.al. 1993)
  - Pre-structured worlds
- Synthetic environments (Tambe 1995)

Multi-Agent Frameworks in Synthetic Environments

- Agents replace humans to:
  - Populate virtual worlds
  - To simulate virtual worlds
- In traffic simulators (Cremer et.al. 1994)
  - Simulating traffic situations
- In situational simulations for the Air-Combat domain (Tambe 1995)
  - The SOAR framework (Laird et.al. 1987)

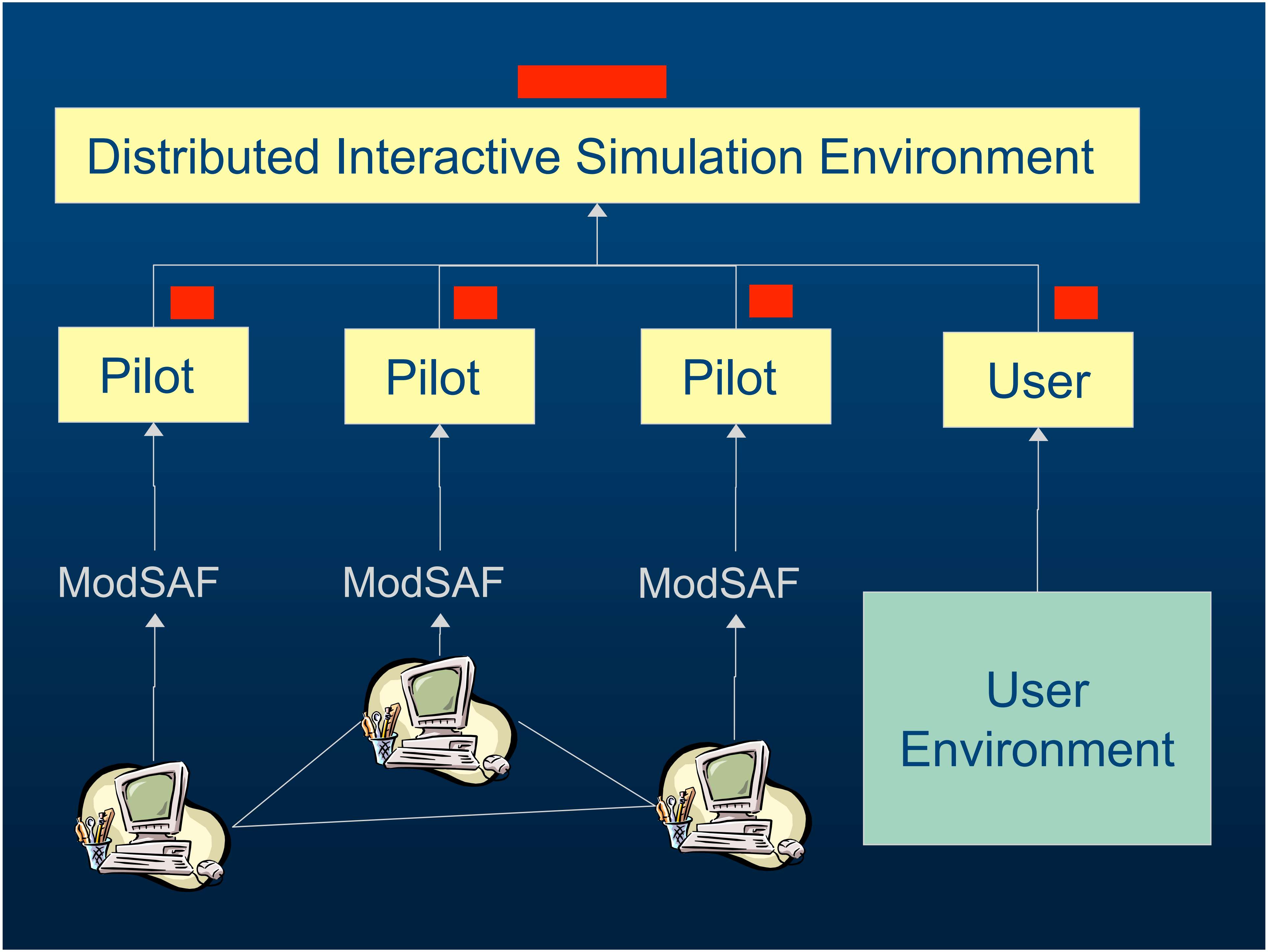
SOAR Framework
(Laird et.al. 1987)

- Time is a sequence of states
- Actions and events are instantaneous
- Pre-determined state space
- Parallel, time consuming events
- SOAR is an FSM language
  - FSM languages are restrictive (Tambe et.al. 1995)

FSM: Finite State Machine

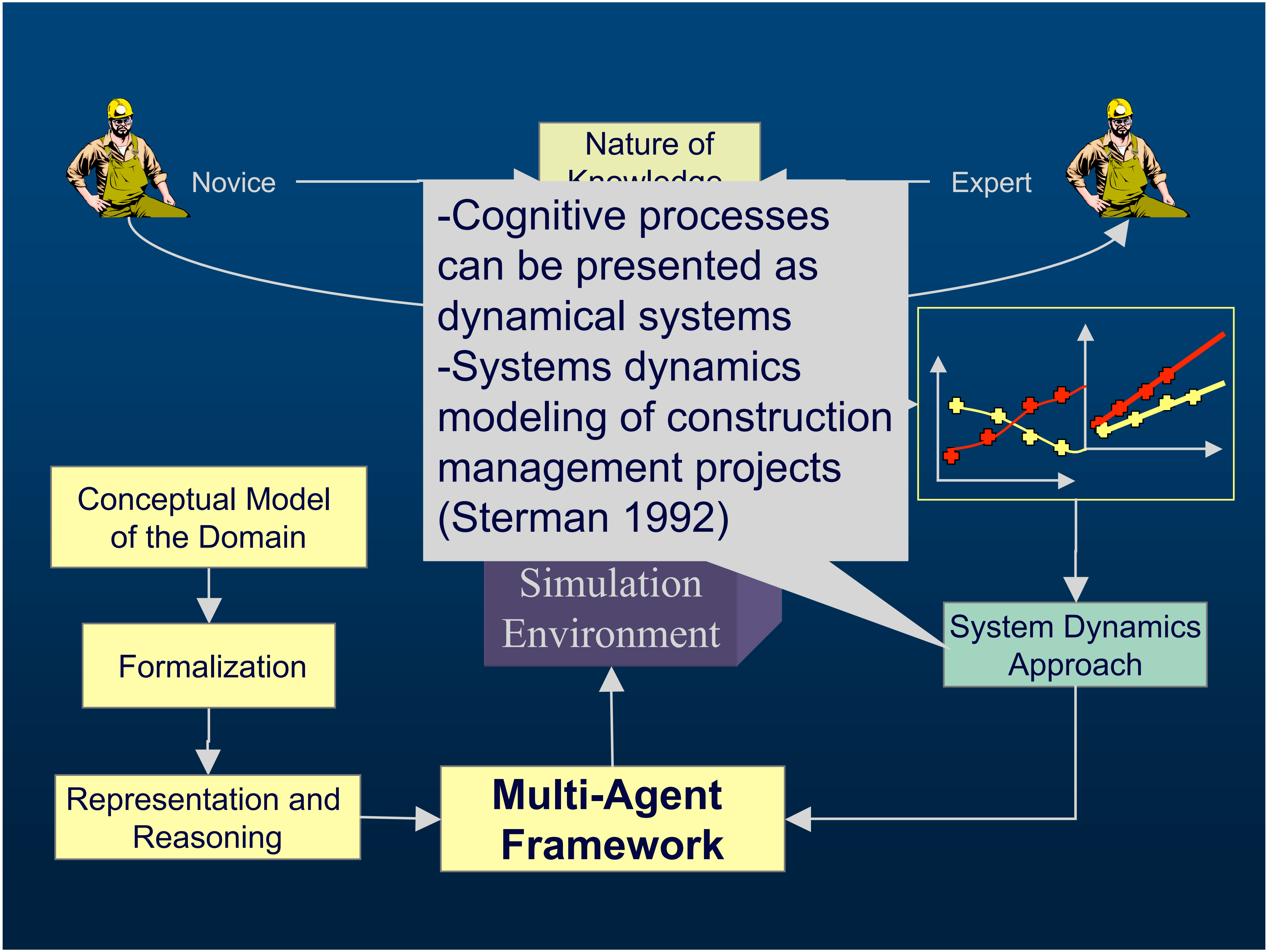
Air Combat Domain: SOAR

- Pilot agents participating in battlefield simulations (Tambe et.al. 1995)
- Using ModSAF (Calder et.al. 1993)
- Use of DIS technology (Distributed Interactive Simulations)
- Built on SOAR: States represent situations


Distributed Interactive Simulation Environment
Pilot
Pilot
Pilot
User
ModSAF
ModSAF
ModSAF
User Environment

Without DIS . . .

- Interval representation of time (Allen et.al. 1994)
- Represent events as intervals triggered by actions
- Each Activity is represented by a FSM
- Parallel activities are parallel FSMs
- Allows multiple events


Nature of
Knowledge
Novice
Expert
-Cognitive processes can be presented as dynamical systems
-Systems dynamics modeling of construction management projects (Sterman 1992)
Conceptual Model of the Domain
Formalization
Representation and Reasoning
Simulation Environment
System Dynamics Approach
Multi-Agent Framework

The Interface

Design

Schedule

Resource Availability

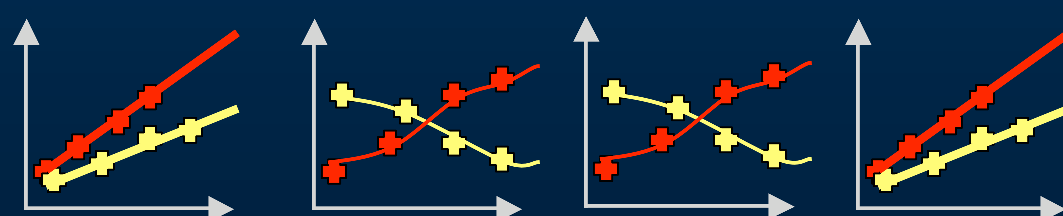
Market Information

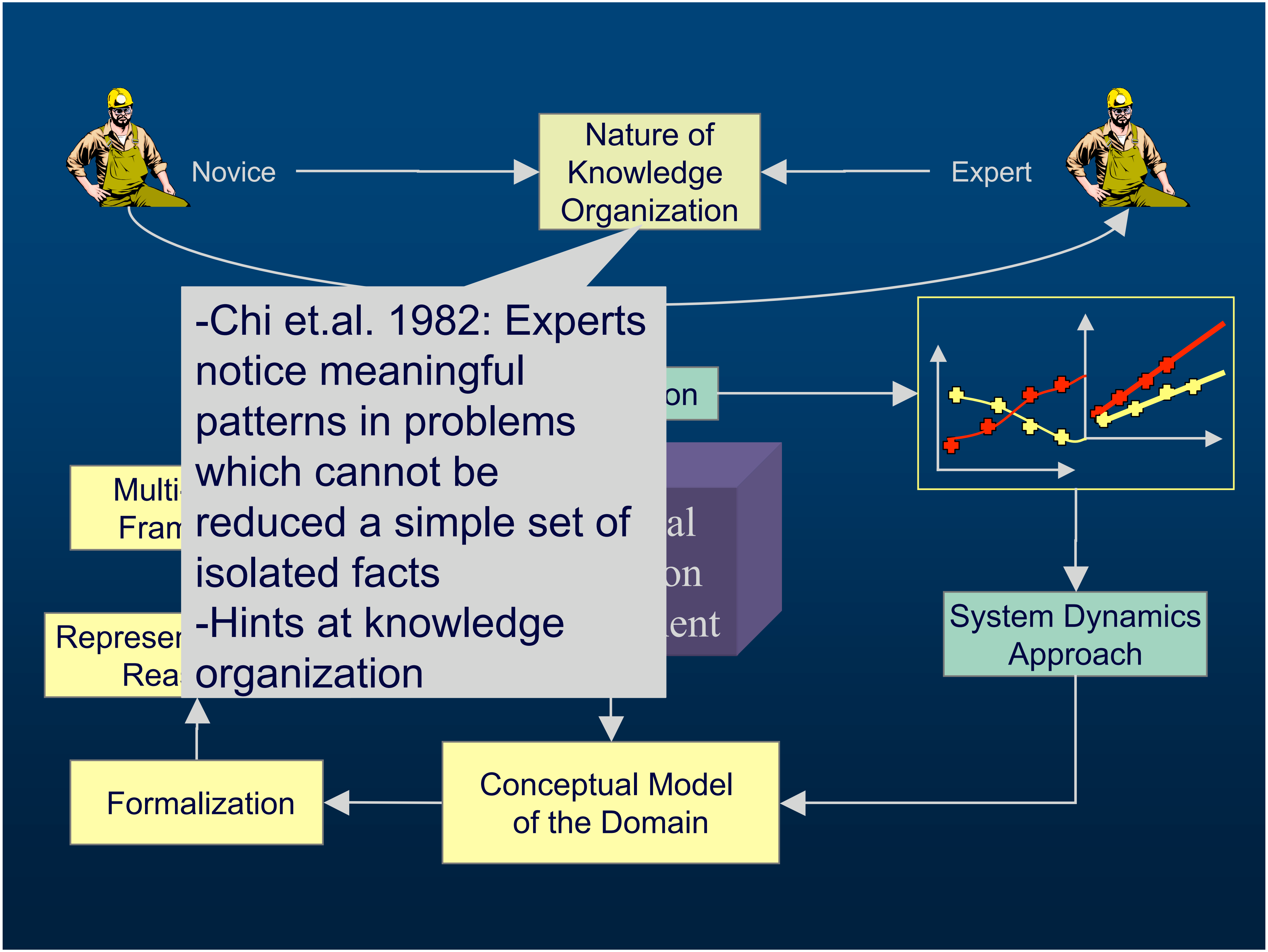
Weather

Viewer 2
Media Files
Images

In-built Web Browser

- Labor - Equip - Mat (Input line)





Novice
Nature of Knowledge Organization
Expert
-Chi et.al. 1982: Experts notice meaningful patterns in problems which cannot be reduced a simple set of isolated facts
-Hints at knowledge organization
System Dynamics Approach
Conceptual Model of the Domain
Formalization

Experimentation & Verification

- Expose expert and novice CM to a prototype of the system
- Elicit opinion from experts
- Verification based on expert opinion
- Type Zero error checks (Shi 2001)

Work Completed

- Development of conceptual frameworks
  - Process, Product and Information Model
  - Mathematical Model (Rojas and Mukherjee, 2003)
  - Problem formulation as a CSP
- Development of a formalism
  - Based on Interval Temporal logic (Allen et.al.1994)
  - Representation of resource and precedence constraints
  - Representation of events and situations

Work Completed

- Implementation of:
  - Dynamic project re-scheduling using precedence constraint and space and material availability constraints
  - Agent reasoning mechanism capable of inferring recent user interactions and predicting future states of simulation environment
- Initial development of Agent Framework
- Initial interaction with expert / novice CM

The Road Ahead

- Complete development of Agent-Entity framework
- Implement a prototype of the proposed general purpose multi-agent framework
- Develop a specific situational simulation to test multi-agent framework
- Continue interaction with expert / novice CM
- Experiment with prototype: Elicit expert opinion

Deliverables

- A prototype general purpose situational simulation environment
- Implementation of a situational simulation of a specific construction project
- Expert opinion

Potential Contributions

- A general purpose environment for educational simulations
- A platform that promotes collaborative efforts in construction education
- An expressive formalism to represent and reason about construction knowledge
- A multi-agent interactive simulation environment
  - for a complex real world domain
  - without using SOAR or DIS technology
- Knowledge organization patterns of construction managers

Limitations of Research

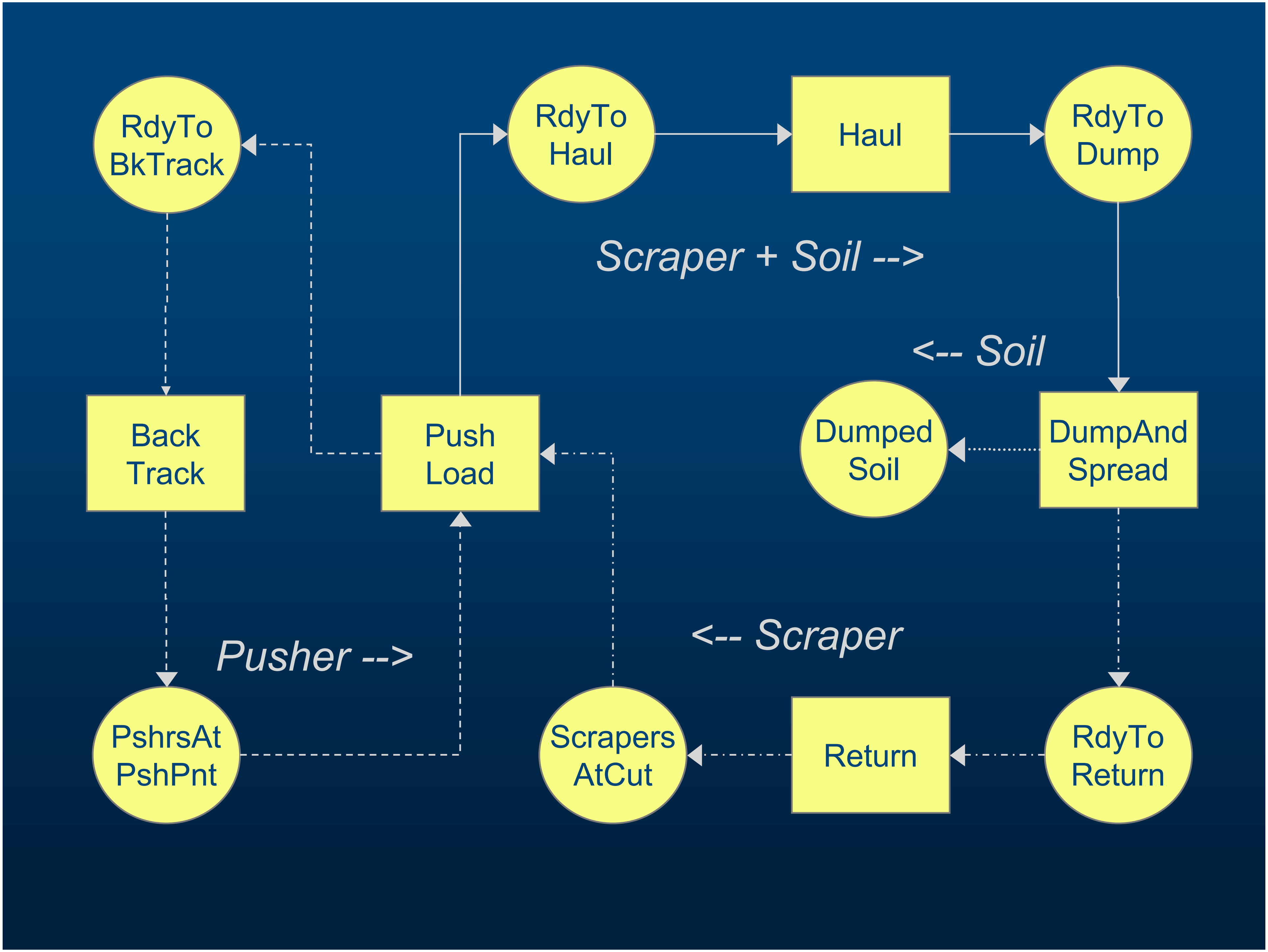
- Agent reasoning is limited by the knowledge base
  - Reasoning limited to conjunctive clauses
- Embodiment, Embeddedness and Adaptation (Winn 2002)
  - This research aims only at embeddedness and embodiment but does not promise adaptive behavior
- Objective testing of the environment is beyond the scope of this research
- The agent entity framework can be used to create a general purpose programming language for construction simulations: Implementation of such a language is beyond the scope of this research

Thank you

Questions?

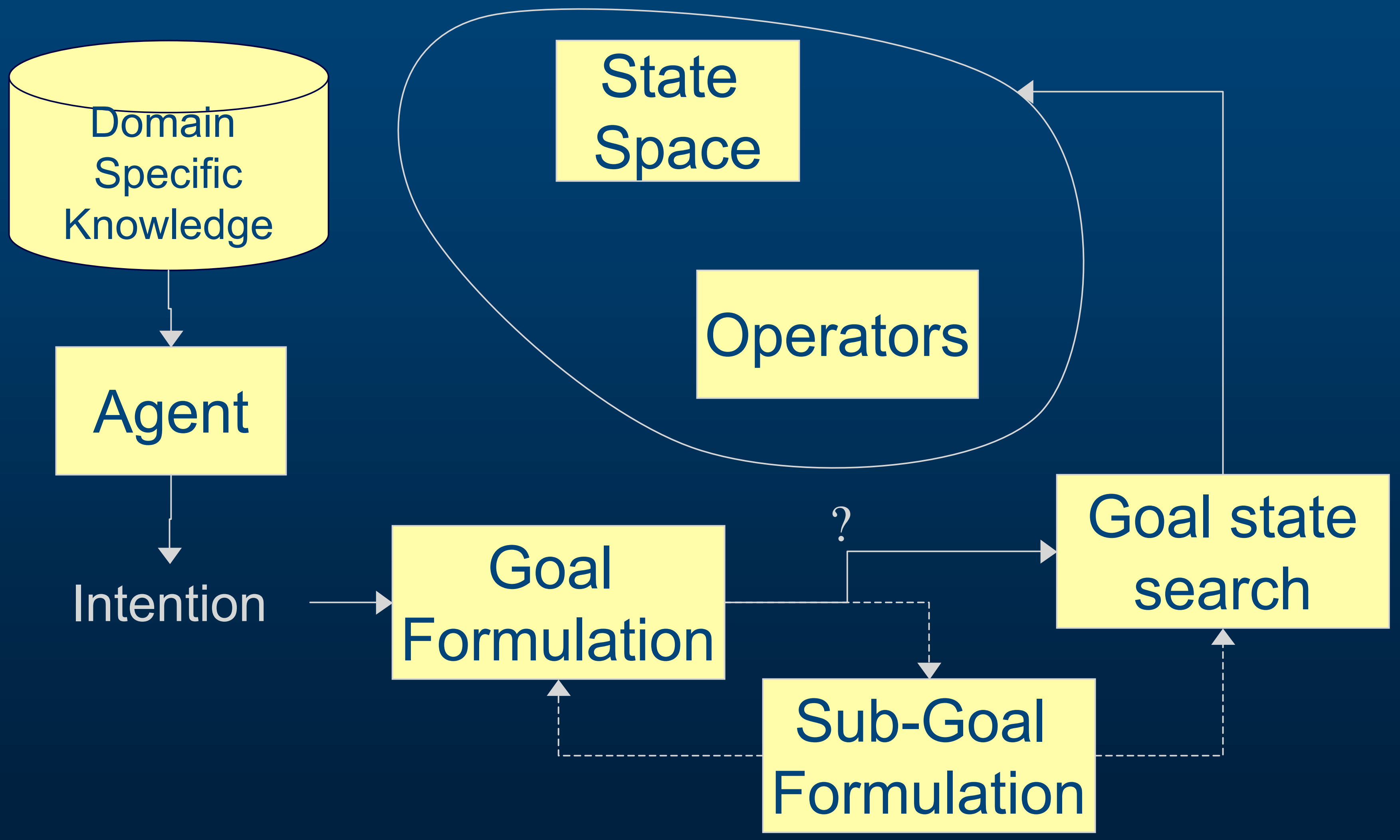
Activity Cycle Diagrams

- Earth Moving Operation Example
- Activities
  - PushLoad
  - BackTrack
  - Haul
  - DumpAndSpread
  - Return



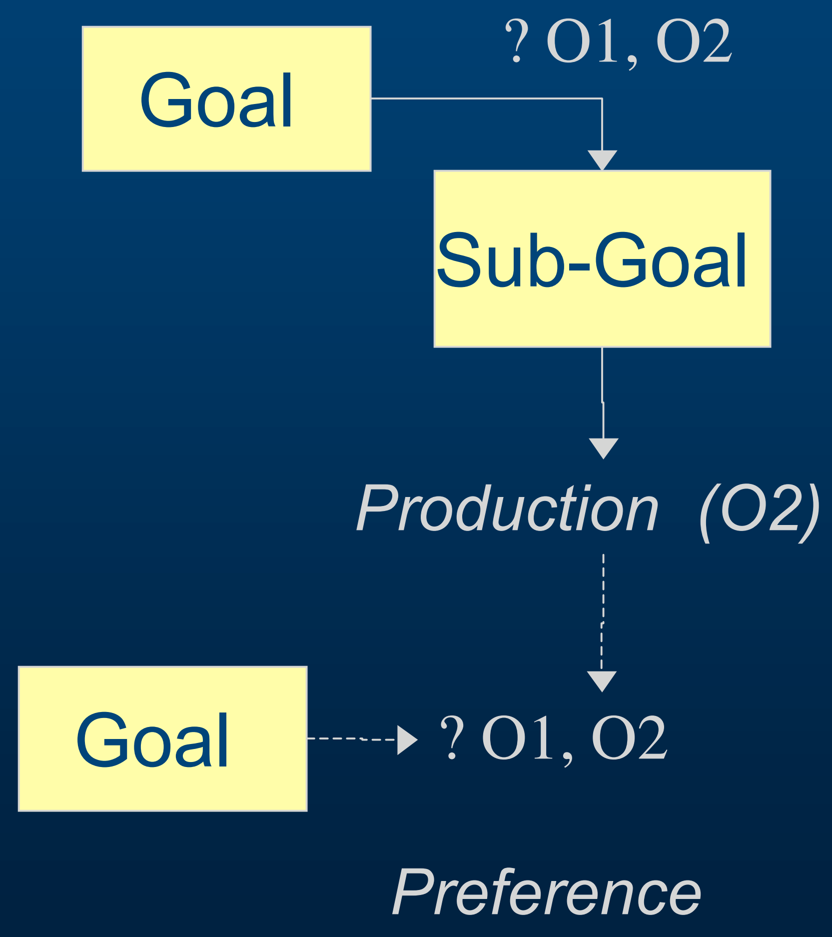
RdyTo BkTrack
RdyTo Haul
Haul
RdyTo Dump
Scraper + Soil -->
<-- Soil
Back Track
Push Load
Dumped Soil
DumpAnd Spread
<-- Scraper
Pusher -->
PshrsAt PshPnt
Scrapers AtCut
Return
RdyTo Return

The SOAR Framework



The SOAR Framework

- Automatic learning using *productions*
- *Productions* provide *preferences*



Finite State Machine

- A Model of computation:
  - Kripke Structure: $\mathcal{M} = <\mathcal{S},\mathcal{I},\mathcal{R},\mathcal{L}>$
- $\mathcal{S}$: Finite set of states
- $\mathcal{I} \subseteq \mathcal{S}$: Set of initial states
- $\mathcal{R} \subseteq \mathcal{S}\ x\ \mathcal{S}$: Transition functions mapping current states to successive states
- $\mathcal{L}$: Language