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**

$t_0$

**Defined Growth Functions/Domain Model**

**Projected Final State**

$t_{++}$

Example: (Martinez, 2001)

**Model input parameters**

- Amount of soil in m$^3$: --
- Truck cost ($/hr$): --

...  

**Calc results after sim.**

- Production rate (m$^3$/hr): --
- Unit cost ($/m^3$): --
- Averages over runs: ---

**Calc results after sim.**

- Production rate (m$^3$/hr): --
- Unit cost ($/m^3$): --
- Averages over runs: ---
Situational Simulations

Rule Base

System

Event 1

Event 2

Event 3

Possibility 1

Possibility 2

Possibility 3

User

Time

t_0
t_1
t_2
t_3
t_4
t_5
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

CONSTRUCTO
  - Halpin (1973)
CEPM Game
  - Veshosky et. al. (1991)
SuperBid
  - AbouRizk (1993)
STRATEGY
  - McCabe et. al. (2000)

General Purpose

Simphony
  - AbouRizk (1993)
EZSTROBE
  - Martinez (2001)

CYCLONE
  - Halpin (1973)
STROBOSCOPE
  - Martinez et. al. (1999)
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*
A general purpose situational simulation environment for the construction management domain can be created using a multi-agent framework.
Situational Simulation Environment

- Problem classification
- CSP + Planning
- Process, Product, Information model formulation
- Mathematical model formulation

Nature of Knowledge Organization

Novice to Expert

Conceptual Model of the Domain

Formalization

Representation and Reasoning

Multi-Agent Framework

System Dynamics Approach

Perception
Situational Simulation Environment

Novice

Nature of Knowledge Organization

Expert

Perception

- Formal definition of simulation environment as a formal axiomatic system

Conceptual Model of the Domain

Formalization

Representation and Reasoning

Multi-Agent Framework

System Dynamics Approach
Situational Simulation Environment

Novice Expert

Nature of Knowledge Organization Perception

System Dynamics Approach

Representation and Reasoning

Multi-Agent Framework

Conceptual Model of the Domain

Formalization

Representation and Reasoning

- Representation of resource and precedence constraints
- Representation of activities, actions, events, and situations
- Logical reasoning about evolution of environment
- Systemic reasoning

System Dynamics Approach
Situational Simulation Environment

Agent

Systemic Behavior

Knowledge base

Agent

Agent

 ✓ Plan evolution of system
 ✓ Act: Simulate events
 ✓ React to user interaction

 ✓ 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
  - ModSAF
- Pilot
  - ModSAF
- Pilot
  - ModSAF
- User
  - 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
- 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**

**Multi-Agent Framework**

**Simulation Environment**

**System Dynamics Approach**

**Nature of Knowledge**
The Interface

Design
Schedule
Resource Availability
Market Information
Weather

Viewer 2
Media Files
Images

In-built Web Browser

- Labor
- Equip
- Mat (Input line)
-Chi et.al. 1982: Experts notice meaningful patterns in problems which cannot be reduced to a simple set of isolated facts.
-Hints at knowledge organization.
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
**Pusher -->**

- **PshrsAt PshPnt**
- **Scrapers AtCut**

**Push Load**

- **RdyTo Haul**
- **Scrapers AtCut**

**Haul**

- **RdyTo Dump**
- **Return**

**RdyTo BkTrack**

- **Back Track**
- **RdyTo Haul**

**Scrapers + Soil -->**

**Scrapers AtCut**

- **Return**
- **RdyTo Return**

**DumpAnd Spread**

- **Dump And Spread**

**Scraper -->**

- **Scraper**
- **<--- Soil**
The SOAR Framework

- **Agent**
- **State Space**
- **Operators**
- **Goal state search**
- **Goal Formulation**
- **Sub-Goal Formulation**
- **Intention**
- **Domain Specific Knowledge**
The SOAR Framework

- Automatic learning using productions
- Productions provide preferences

Diagram:
- Goal
  - Sub-Goal
    - Production (O2)
    - Preference
  - Goal
    - ? O1, O2
Finite State Machine

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