Using ACT-R to Enable Stochasticity, Spatial Awareness, and Knowledge Generalization in MOUT Agents

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Project Goal: Virtual MOUT Agents Demonstrating Adaptivity, Reactivity, Complexity and Plausibility

- We need agents that are…
  - more independent, robust
  - more adaptive to new situations
  - less computationally demanding
  - more plausible
  - harder to game (more transfer to real world)
  - less predictable, more variable (e.g. different capabilities, cultural attributes, etc)

- Approach:
  - Use the ACT-R cognitive architecture for human behavior representation
  - Use the Infiltration mod for Unreal Tournament as a virtual environment

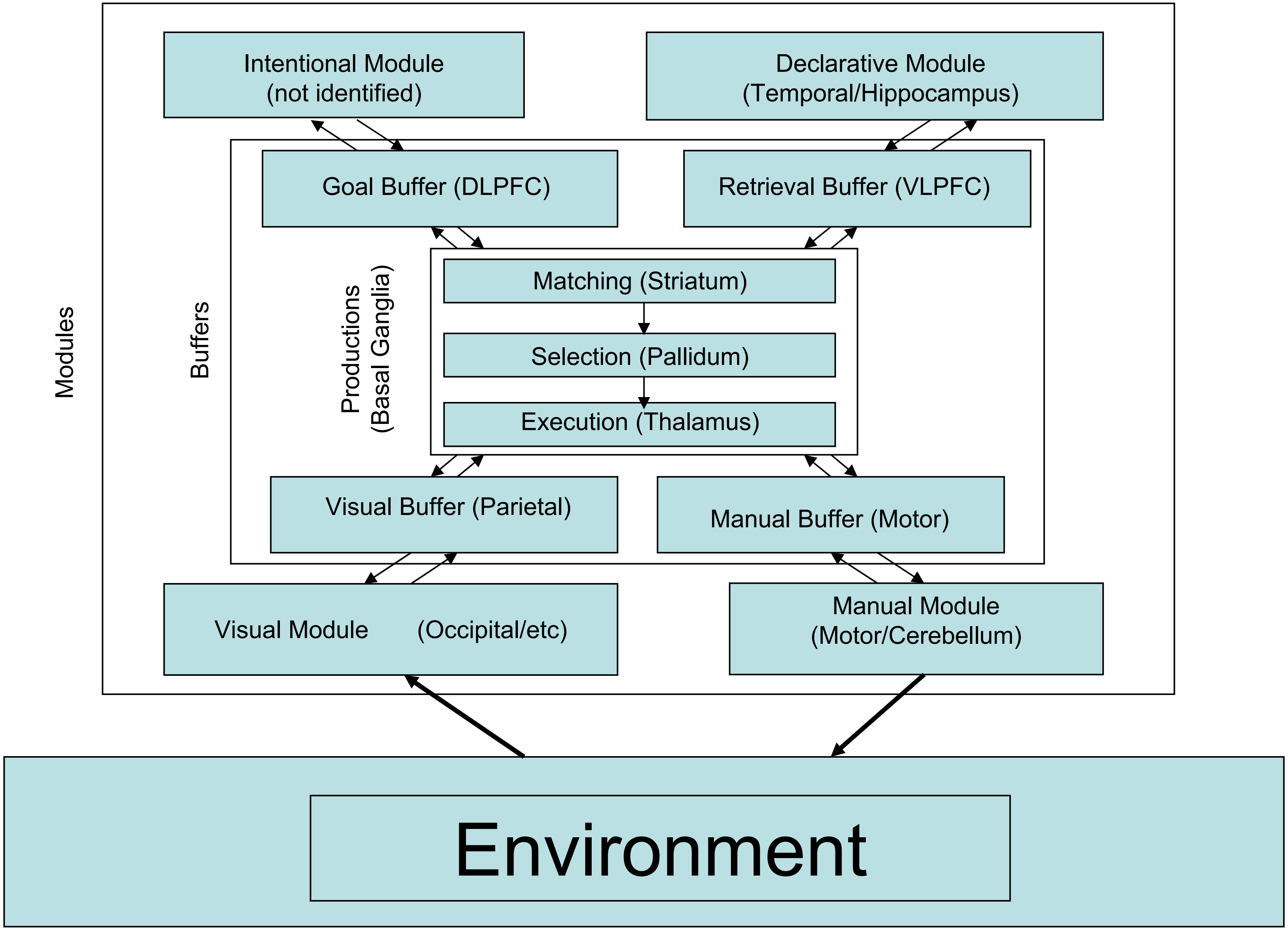
Grounding Agents in a Cognitive Architecture Overcomes Limitations

- A *cognitive architecture* is an empirically derived and validated development framework for simulating human behavior, such as planning, problem solving, and decision making, in complex tasks
- Why a cognitive architecture?
  - Affordable: mechanisms (learning, perceptual, pattern matching, etc) are built-in so capabilities can be expressed at a high-level
  - Validated: human limitations and capacities are built in, which ensures plausibility of agent
    - Broad user community has validated the architecture against a wide range of empirical results and continuously extends the architecture to account for new findings
  - Leveraging others work: reuse parts of models and paradigms develop by user community

The ACT-R Cognitive Architecture Provides a Mature and Comprehensive Platform

- Maturity: Framework has been in use for 20+ years
  - HAM (1973) -> ACT-E (1977) -> ACT* (1978) -> ACT-R (1993)
- Fundamentals of architecture:
  - Integrates perceptual, motor and cognitive modules to provide situation awareness
  - Hybrid of symbolic (rule-based systems) and sub-symbolic (neural networks) processes provides best of each approach
  - Simulates human capacities for learning, memory, and perception
  - Grounded in broad empirical findings of cognitive psychology
  - Goal-directed behavior is a basic primitive
    - Productions match goals against contents of goal buffer
  - Effects of individual differences and behavior moderators (fatigue, motivation, etc) can be modeled through principled parameter variations

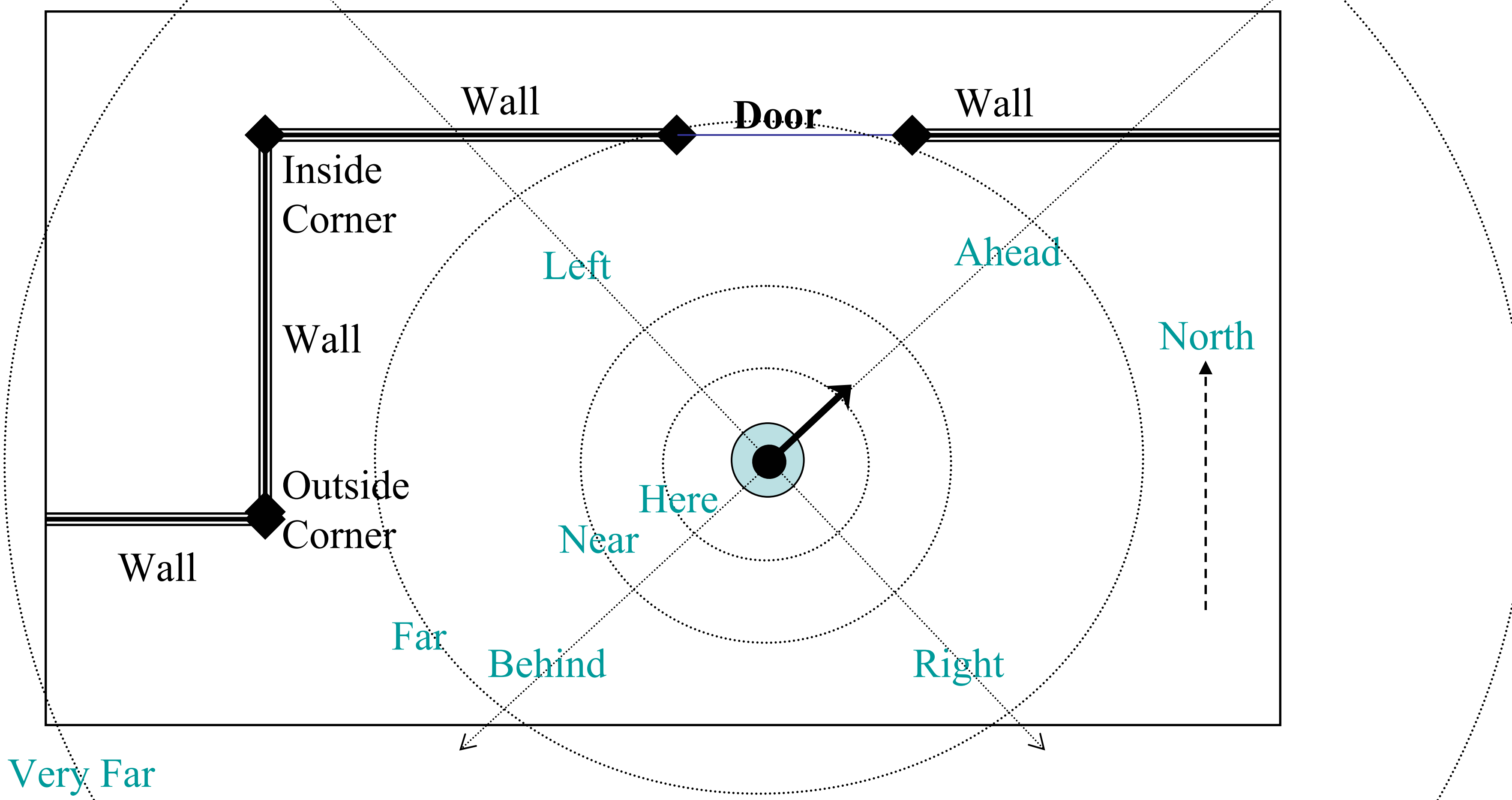
ACT-R 5.0 Architecture



ACT-R MOUT Agent Contributions

- Plausible spatial awareness and navigation
  - Avoid predictiveness of point-based navigation
  - Cost-effective (automated) encoding of maps into model
  - Plausible situational awareness
  - *Modeling of human limitations such as disorientation, forgetting*
- Behavioral transparency
  - Direct encoding of MOUT doctrine at symbolic level
  - *Can be automated through graphical authoring tool*
- Behavioral variation
  - Stochasticity built into the architecture at all levels
    - does not repeat behavior but instead provides breadth of training
  - Provides diverse training experience from limited number of scenarios
  - *Adaptivity: adapts tactics on the fly to behavior of trainee*
- Behavioral generalization
  - Knowledge generalizes to similar situations
  - Robustness: agent does not fall into black holes but instead generalizes knowledge to new situations
  - *Provides robust agent behavior for unconstrained simulation*

Agents Use a Psychologically Plausible Representation* of the Space Around Them:

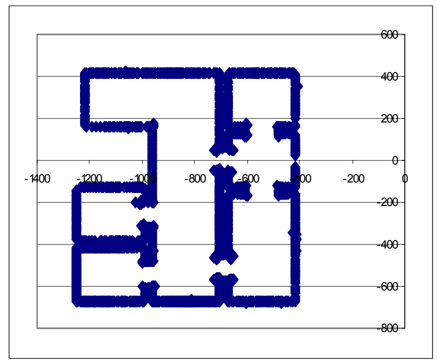


*Declarative memory is constantly updated to maintain a set of elements corresponding to both dynamic and static visible and audible components of the environment.

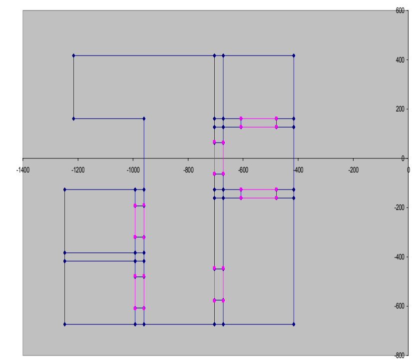
Automatic Mapping Agent Generates Representation

Step 1: Agent explores area collecting range-sensor data

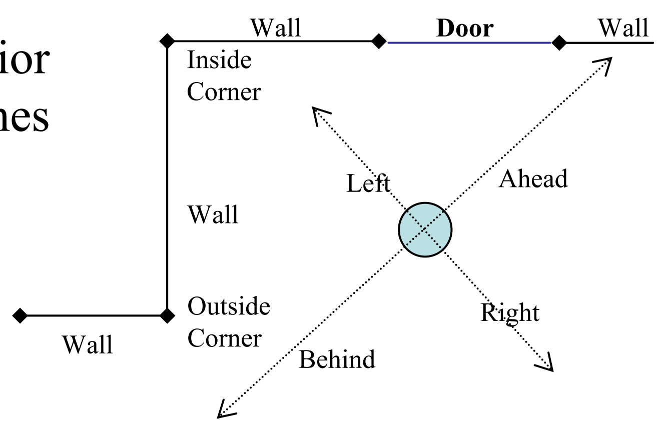
Step 2: Range-sensor data is analyzed



Step 3: Data is converted to a high-level representation



Step 4: Agent uses representation to reason about its environment



Step 5: Complex agent behavior such as ability to plan ambushes

Benefits of Plausible Spatial Representation

- Spatial awareness is encoded in a form that makes sense to SMEs
  - Architectural buffers hold current set of elements in awareness
  - Includes (some of) what is visible (e.g. enemy, state of self, goal)
- Representation is similar to that used in MOUT doctrinal manuals
  - Symbolic description: knowledge is inspectable
  - Abstract/NL description: e.g. production cond. “if enemy is to left of self”
- Behavior is robust
  - Pitfalls of waypoint-based navigation (e.g. stuck in doorways): moving wrt points in space, not features of architecture (e.g. obstacles)
  - Limited to actions that make sense in immediate visual environment (e.g. won’t try to move to doorway they can’t see)
- Transferring knowledge from SMEs and doctrinal manuals to agents is straightforward
  - No need for change in representation
  - Authoring tool is similar to doctrine diagrams

Spatial Awareness Used in Ambush

Behavioral Transparency: Action Plans Correspond to MOUT doctrine

- **Example**: doctrinal plan to clear an L-shaped hallway
  - Step 1: To clear an L-shaped hallway, the team leader first moves to the inside corner
  - Representation from model* of this step in the plan:

(plan-clear-L-shaped-hallway-leader-step-1

isa action-plan

plan clear-L-shaped-hallway

index 1

role leader

type move

argument inside-corner)

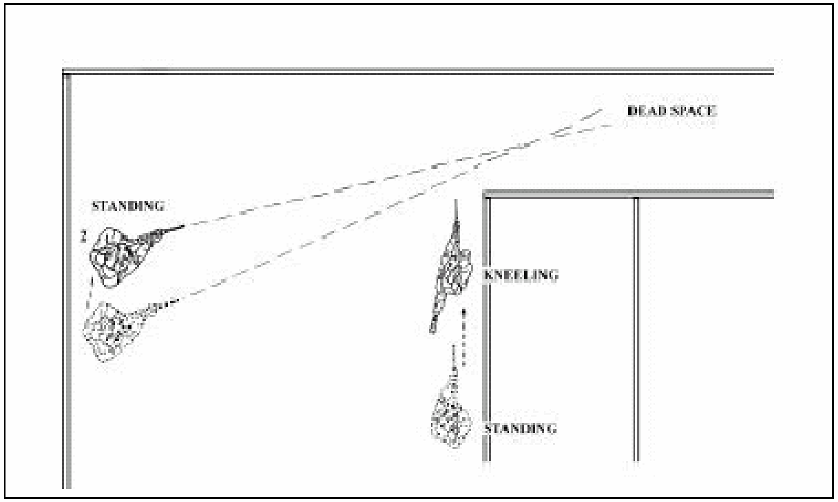


Figure A-45. Clearing an L-Shaped Hallway

*Representation proudly plagiarized from existing model of human sequence learning performance

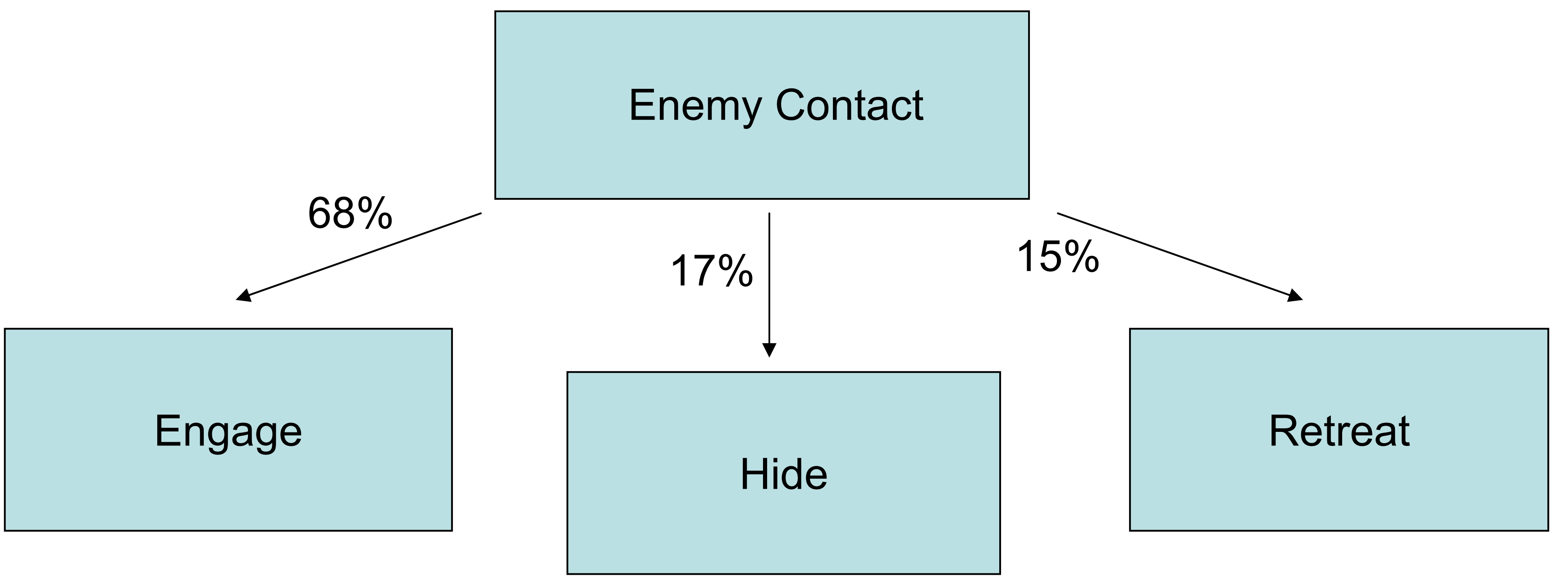
2-Squad Clearing L-Shaped Hallway

Variable Behavior is the Key to Flexible, Realistic Opponents

- Behaviors may range from completely determined by the situation to completely arbitrary, as appropriate
  - Highly practiced behaviors tend to be less variable
  - Variation may be tuned at the level of individual actions or the whole simulation
- Even simple scenarios may play out differently each time
  - This creates greater realism without the extra work of designing more scenarios
  - Variation in selecting among possible actions is key, with the more likely actions emphasized while the less likely ones are still possible

Noise and Stochasticity in ACT-R Automatically Yields Variation of Behavior

- Upon noticing an enemy, an ACT-R agent may choose one of several behaviors
  - Symbolic information and sub-symbolic information interact to shape decisions



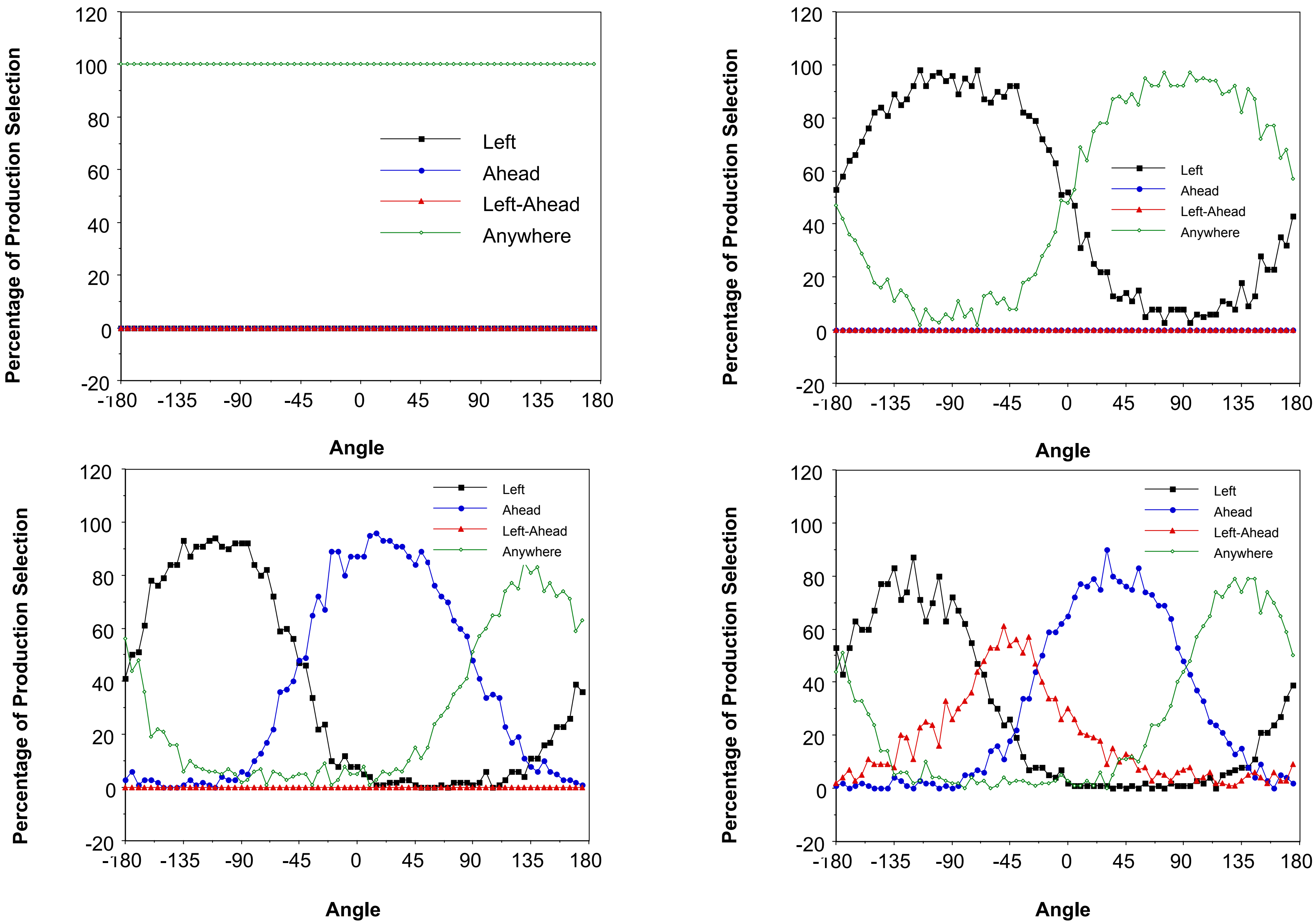
Knowledge Generalization Problem

- Difficult to specify exact range of applicability of rules
- In dynamic, approximate and uncertain environments, symbolic conditions are often too coarse and limited
- Need something like the human ability to generalize a given technique to a flexible range of situations
- Combinatorics of many conditions create excess rules
- Large rulesets need to be painstakingly prioritized to manage interactions between pieces of knowledge
- Adding to knowledge base may require significant redesign due to interactions of new and old knowledge

A Knowledge Generalization Solution

- Make production rules selection depend on *similarity* to canonical example as well as *utility*
  - Exploit ACT-R hybrid nature to combine those quantities
  - Similar to memory partial matching, fuzzy logic, and neural networks
  - Sensitive to learning of a production utility
  - Sensitive to breadth of knowledge in given area
  - Substantially reduces complexity (number of conditions) and number of rules
  - New knowledge integrates with old

New Knowledge Fits with Old



Summary of ACT-R MOUT Bot Capabilities

- Supports **VIRTE** Demo 2 (MOUT Training)
- Capabilities added:
  - Entities **follow MOUT doctrine** (USMC)
  - Entities **negotiate shooter/covering roles**
  - Entities create **spatial maps** of their surroundings
    - Create unfolding spatial maps **on the fly**, as when in unfamiliar surroundings
    - Knowledge base detailing layout of doors, walls, openings automatically created out front, simulating familiarity with surroundings, or accumulated through experience
  - Entities capable of line-of-sight targeting and understand concepts such as **cover and concealment**
  - Capable of using spatial knowledge to **plan ambushes**
  - Single or multiple computer control of interacting entities that **communicate spatial knowledge** of structures and adversaries

Gold Nuggets: What is ACT-R Making Easy?

- Representation
  - Declarative/Procedural distinction
    - Plans are declarative, transparent
    - Actions are non-verbalizable
- Plausible memory and perception (imperfect)
  - Plan following, forgetting
  - Perception (visible items are subset of declarative memory)
  - Imperfect memory for visited locations
- Sub-symbolic (neural level)
  - Stochasticity
  - Partial matching
  - Production generalization and specialization

Lumps of Coal: What is ACT-R Making Hard?

- Integration with applications
  - Intervening software layer
  - LISP: garbage collection and real-time constraints
- Software engineering
  - Modest debugging tools
  - Practical limits on size of production set
    - No rete net
  - Difficulty in tracking down performance problems (many suspects, no smoking guns)
- Metacognition lacking
  - What was the bot do<u>ING</u> for the last few seconds, minutes?
    - Not the same as knowing what the current goal is

From Where is ACT-R Coming, To Where is it Going?

- Purpose: to account for empirical data
  - Roots in memory experiments 20+ years ago
  - This includes accounting for intelligent, goal-directed human behavior
- Procedural/Declarative distinction
  - Anonymous member of Soar/ACT-R Community: “I still don’t believe in the procedural/declarative distinction, but you should keep it in, it’s useful.”
- Symbolic/Sub-symbolic distinction
  - Sub-symbolic level is stochastic
  - Game playing (e.g., rock, paper, scissors) enhanced by stochastic behavior
- Theoretical validation at neuroscientific level
  - Many theories can predict behavioral data, but collection of neuroscientific data may sort them out

References

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