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Autonomy Protocols: From Human Behavioral Modeling to Correct-by-Construction, Scalable Control

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Project Objective:

Develop scalable, automated methods for the synthesis of autonomy control protocols with provable correctness guarantees, incorporating insights from models of human behavior.

Novel empirical and mathematical insights on how humans manage complexity
- guide architectural exploration for effective hierarchical decompositions
- couple control and sensing/perception

Decision-making hierarchies identified as "promising" by developing correct-by-synthesis protocols from
- formal temporal logic specifications
- customized algorithms for robust, constrained optimal control

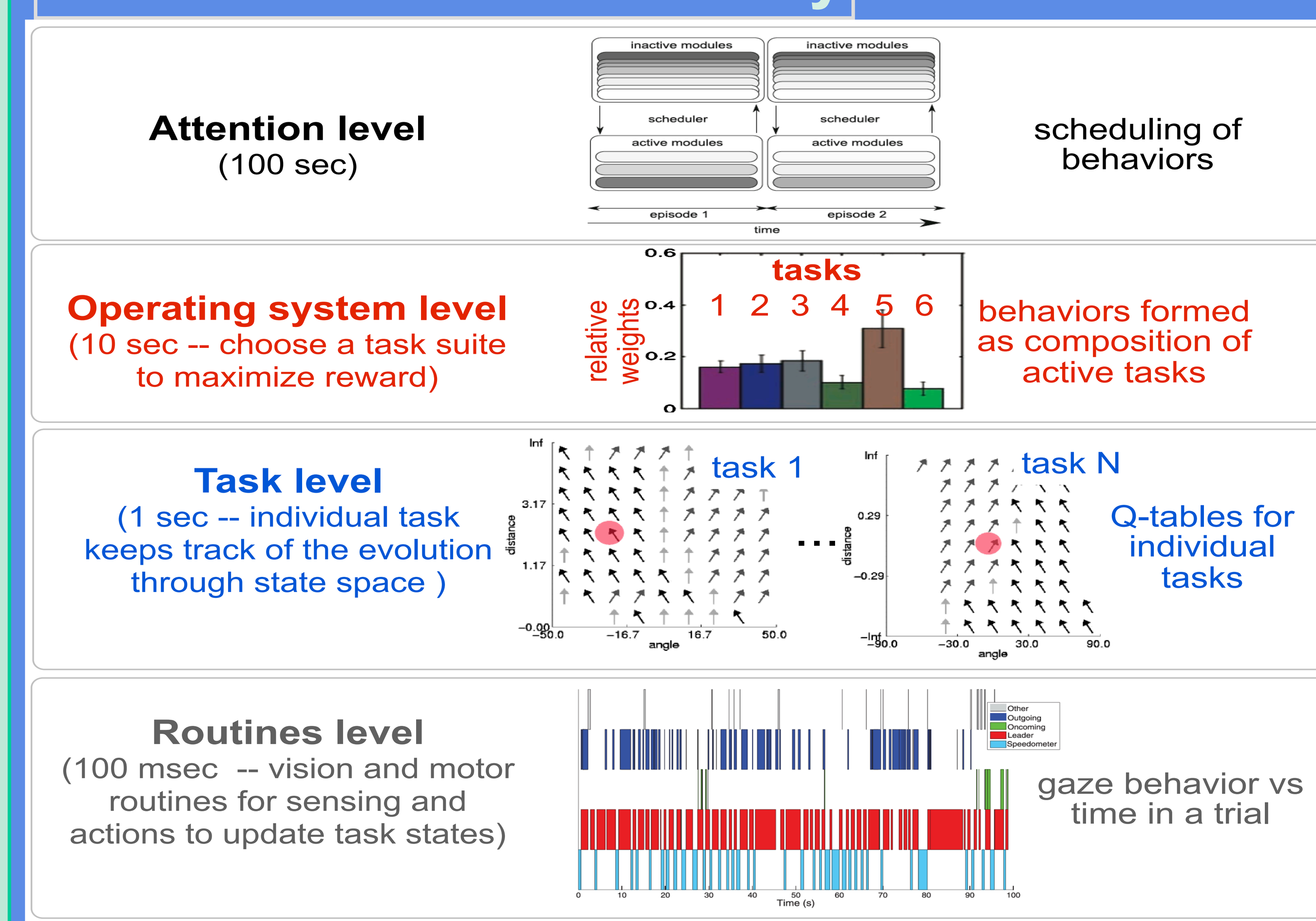
for verifiably reliable real-time implementations

Key Observations:

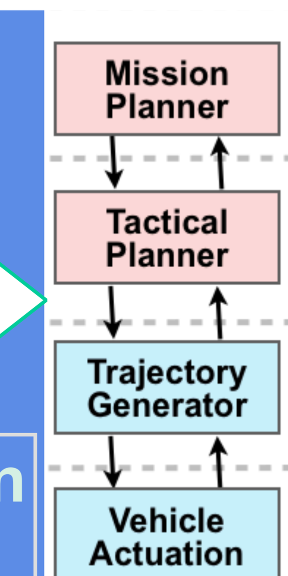
- Human decision-making is observed to have a modular hierarchical decomposition
- Modular Reinforcement Learning (**RL**) provides a systematic way to model human behavior
- Temporal Logic (**TL**) based mission/tactical planning systematically ensures "correctness" of autonomy
- Real-time optimization based motion control can implement mission plans in the physical domain
- Online abstractions of constrained motion control via reachability sets provide inter-layer consistency

Merging these capabilities under a single synthesis framework can enable a leap in autonomy by
- Significantly increasing the fidelity of models used in decision-making
- Reducing the conservatism of the autonomy protocols without sacrificing tractability and correctness

Human Decision Hierarchy

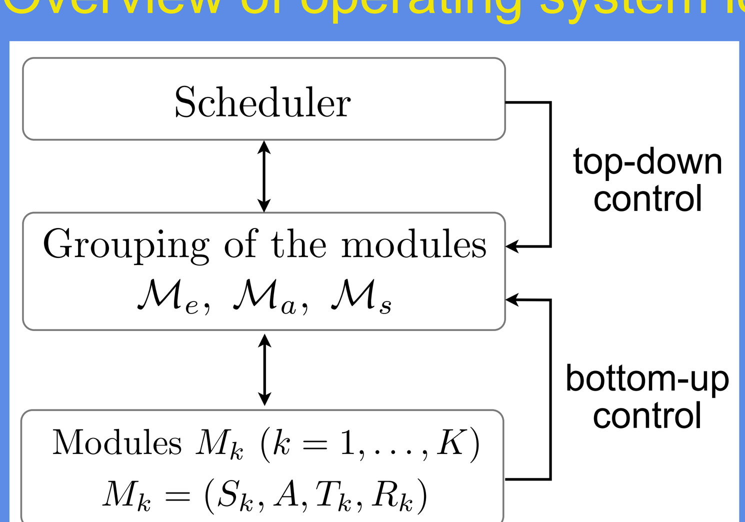


How can insights from human behavior can be leveraged to manage complexity and uncertainty in autonomous decision-making? ?

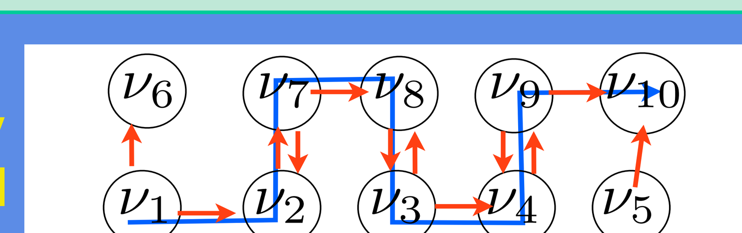


Autonomous Decision Hierarchy

Overview of operating system level



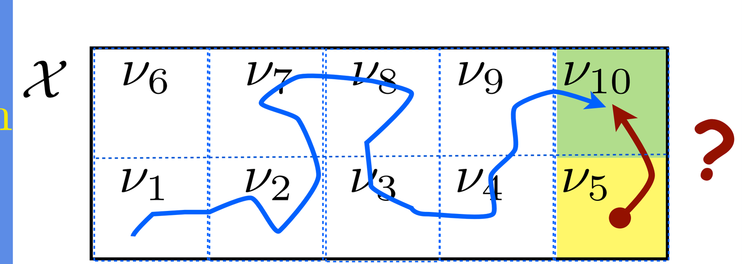
Robust set-to-set reachability for abstraction of the physical layer



Planning space and specification

$\Diamond A \wedge \Box\Diamond B \wedge \Box\Diamond C \wedge \Box S$

$\Diamond$ and $\Box$ are eventually and always



Thrust-I: Modeling of human sensory-motor decisions and empirical assessment of the candidate decision-making architectures

- How do humans decompose decision-making?
- How do we represent this decomposition?

Thrust-II: Integrating architectural insights into decision-making

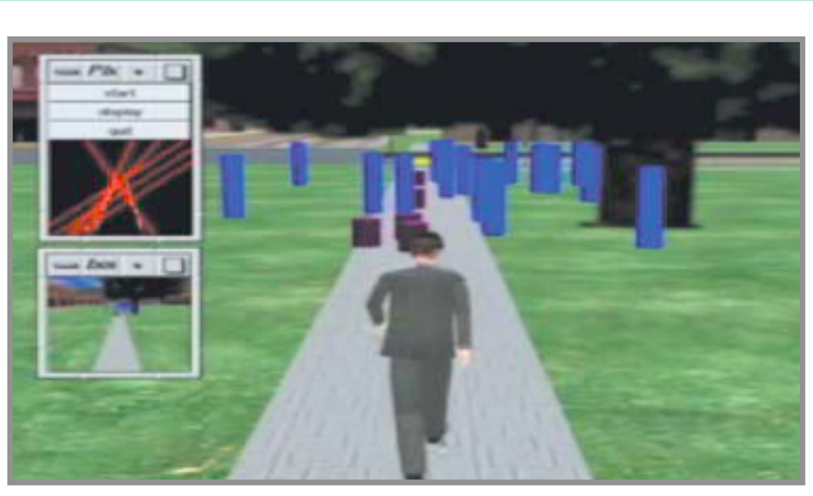
- How can synthesis problems be generated?
  - Models and constraints
  - Specifications and information flow
- How can we ensure inter-layer consistency?

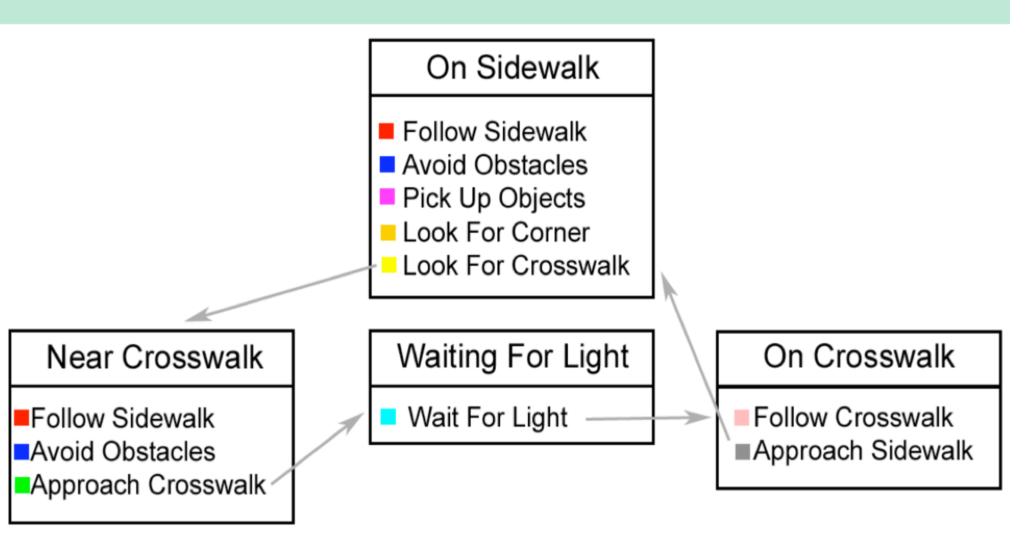
Reliable custom solvers enabling real-time computations

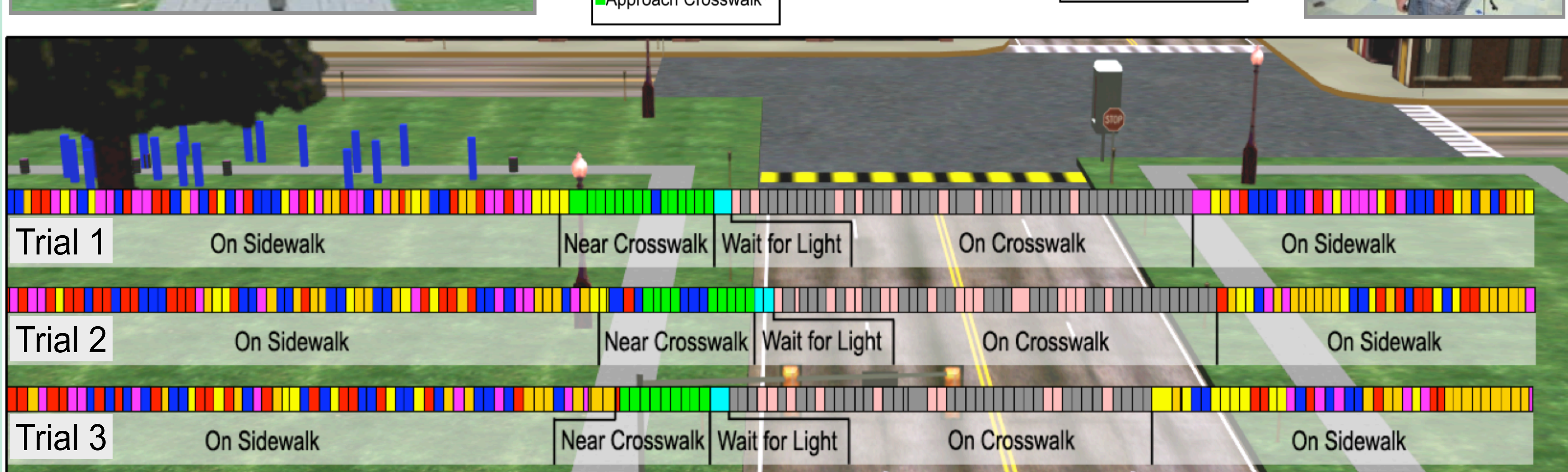
Method	SQP	IPM	Custom IPM
CPU time (m-secs)	20,000 – 30,000	2,500 – 3,000	12 – 15
Reliability	75 – 80%	>99.9%	>99.9%

Thrust-III: Reliable run-time computational engines for motion planning and abstraction

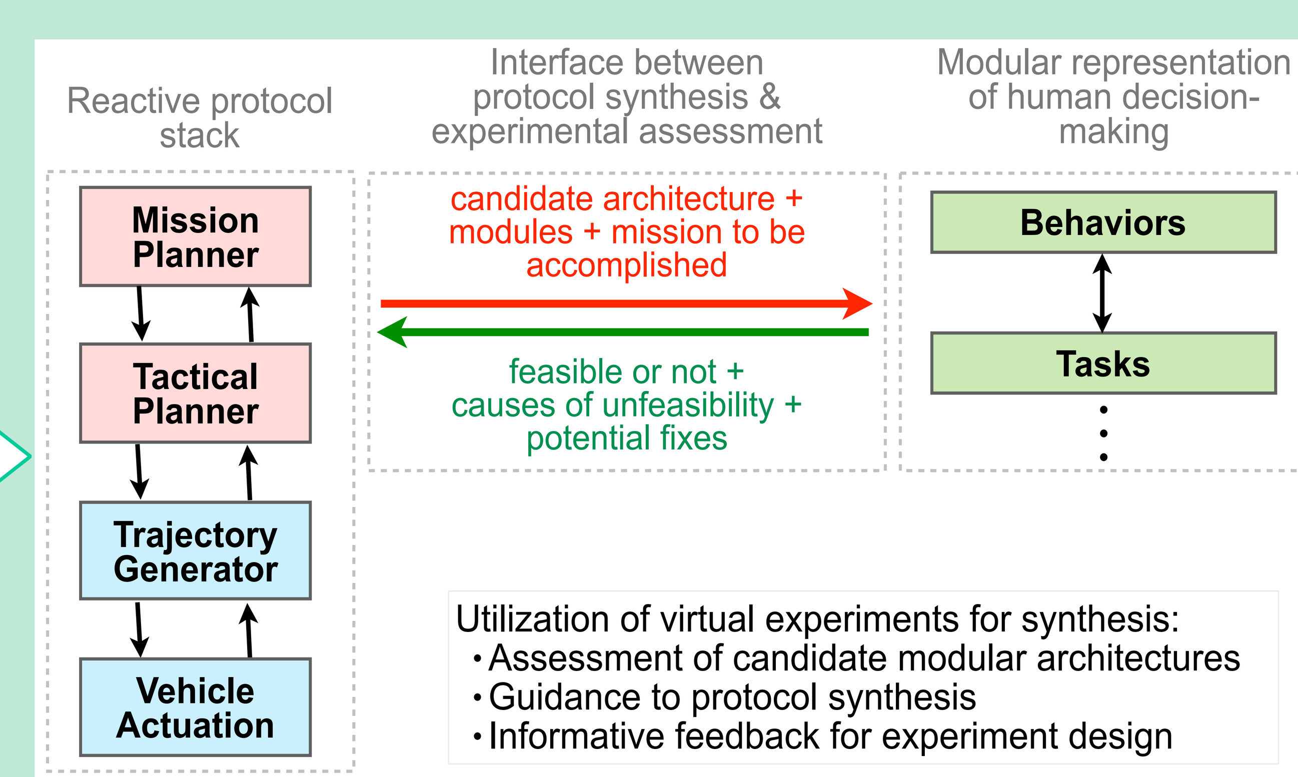
- How can we incorporate uncertainty and constraints?
- How can this process be abstracted?
- How can the computations be done in real-time?







Virtual Environment Testing for Modular Decision Architecture



Integration of Experimental Results into Algorithmic Tools for Autonomy

Broader Impact

- Autonomy is a capability with stand-alone applications such as UAVs
- Also embedded into numerous other instantiations of cyber-physical system

We target
- the gap between current autonomy capabilities and the levels at which they can impact our use of resources
- the lack of systematic design methodologies toward highly capable and scalable autonomy protocols

Team