A Logical Framework for Self-Optimizing Networked Cyber-Physical Systems

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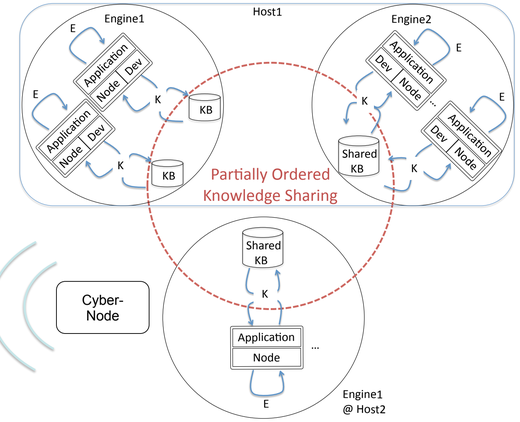
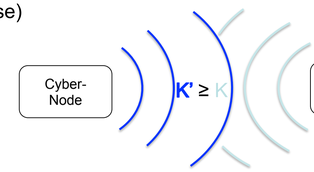
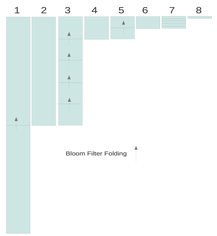
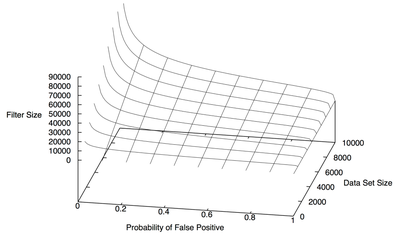
An Application Framework for Networked CPS

- Based on new loosely-coupled distributed computing model:
  Partially Ordered Knowledge Sharing
- Inspired by our earlier work on delay-/disruption-tolerant networking (DTN)
- Minimal assumptions on network connectivity (can be very unreliable)
- Designed for heterogeneous networking technologies and heterogeneous nodes
- Partial order allows the network to replace obsolete, subsumed, or inferior knowledge (semantic broadcasting)
- Global consistency is not enforced (impossible in challenging environments)
- Avoids strong non-implementable primitives, e.g. transactions
- Investigating dissemination of cache (knowledge base) summaries using Bloom filters
  - dynamically folding/unfolding a Bloom filter
  - careful off-line planning of the folding/unfolding
  - adaptive entropy-aware on-line folding/unfolding





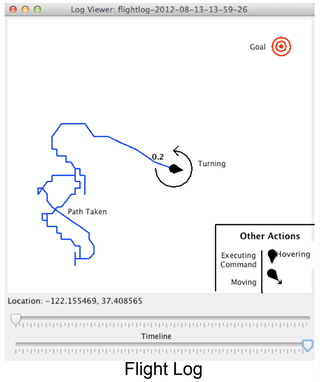




A modified quadcopter controlled by the cyber-application framework

Four quadcopters controlled by cyber-framework on one base station

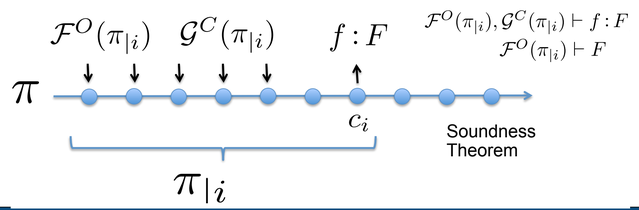
Modified Parrot AR Drones with GPS, digital compass, Linux Gumstix, and WiFi

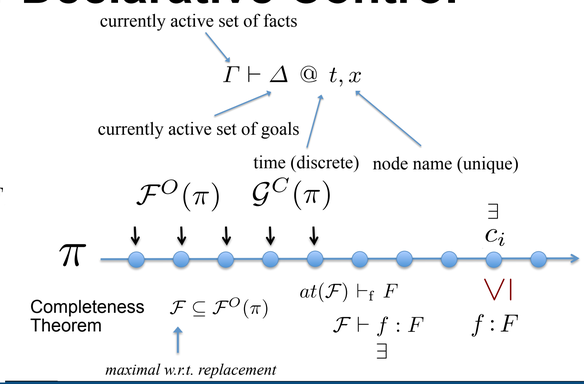


Flight Log

Distributed Logic for Declarative Control

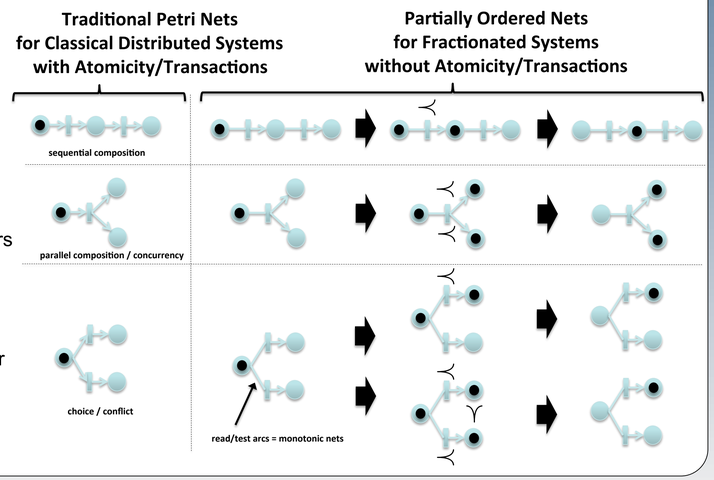
- Truly distributed logical framework with explicit proof objects
- Cyber-predicates enable interaction with the physical world
- Facts and goals treated on an equal footing
- Covers entire spectrum between autonomy and cooperation
- Tested with abstract mobility model and Stage multi-robot simulator
- Soundness, Completeness, and Termination Conditions





Workflows of Cyber-Physical Ensembles

- Theory of a new distributed computing model for cyber-physical dataflow, controlflow, and workflow
  - a first step toward a model-based design methodology for Networked CPS
  - a distributed execution engine that exploits the parallelism of the underlying cyber-framework
  - cyber-nodes cooperate by emitting waves of knowledge indicating local progress
  - Implemented on top of the partial-ordered knowledge-sharing model
- Partially ordered net is defined by replacement orders
  - causal replacement (to move forward in time)
  - conflict replacement (to resolve inconsistency)
- Key features: redundancy and diversity of many unreliable and potentially heterogeneous networked components is exploited to improve scalability, better performance, and reliability
- Possible next steps:
  - an experimental real-world deployment in our testbed (e.g., formation flight of quadcopters)



Distributed Control Utilizing Virtual Potentials

- Simulation of UAV swarms in the cyber-application framework
  - uses artificial physical laws with dynamics guided by local forces: attractive when too far, repulsive when too close.
  - leads to global regular configurations (e.g., hexagonal lattice).
  - research question: can this idea be generalized to a universal declarative approach with a high-level specification in form of potential functions ?
- Virtual potential field
  - each agent is driven by the desire to minimize its perception of and hence its own contribution to the virtual potential
  - independent of the size of the ensemble, naturally and dynamically scalable, and robust under failures
  - declarative in the sense that the virtual potential can be seen as a specification of the desired state of a system
- Distributed surveillance mission by a swarm in formation
  - the potential field needs to be designed to guide the UAVs' formation and to be adaptive when a new target location is selected.
  - to cope with local minima, we use a distributed version of simulated annealing.