Collaborative Autonomy and Human-Robot Teams

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THIRTY YEARS OF SYSTEMS RESEARCH EXCELLENCE

INSTITUTE FOR SYSTEMS RESEARCH
A. JAMES CLARK SCHOOL OF ENGINEERING

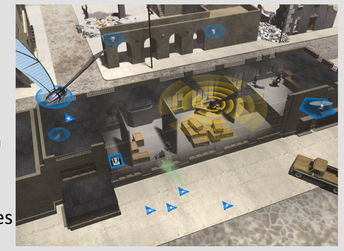
Joint Control and Communication Design for Autonomous Heterogeneous Robot Teams

New capabilities

- Concurrent design of mobility and communication policies
- Extend situational awareness capabilities by enhancing connectivity

Technical challenges

- Harsh (lossy) environments result in poor connectivity
- Modeling radio propagation in urban environments
- Lack of predictive capabilities makes it difficult to plan/ control



Interpretation of the Generalized Consensus of Opinion Algorithm

The **general consensus algorithm on convex metric spaces**

$$X_i(k+1) = co(X_j(k), j \in N_i)$$

$$X_i(k+1) = \sum_{j \in N_i} \mathbb{1}_{\{\theta=j\}} X_j(j), \quad Pr(\theta_i = j) = w_{ij}, \ \sum_{j \in N_i} w_{ij} = 1$$

Theorem(Matei, Baras 2010) If the communication graph of the agents is connected, then there exists $x^* \in X$, such that

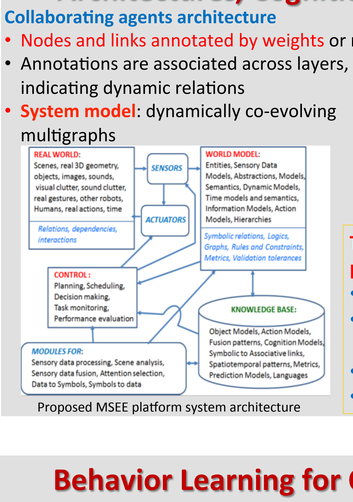
$$\lim_{k \to \infty} d(x_i(k), x^*) = 0$$

Interpretation: The consensus of opinion algorithm has the same interpretation as the linear consensus algorithm on $\mathbb{R}^n$, *i.e.* $X_i(k+1)$ is chosen from the (generalized) convex hull of $\{X_1, X_2, \ldots, X_n\}$.

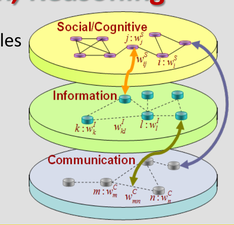
Collaborative Autonomy: Architectures, Cognition, Reasoning

Collaborating agents architecture

- Nodes and links annotated by weights or rules
- Annotations are associated across layers, indicating dynamic relations
- **System model**: dynamically co-evolving multigraphs



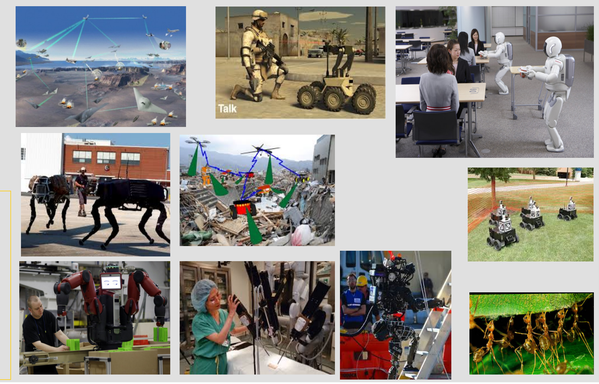
Proposed MSEE platform system architecture

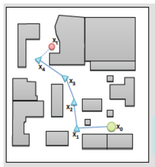


Task-driven integration of perception, control, language

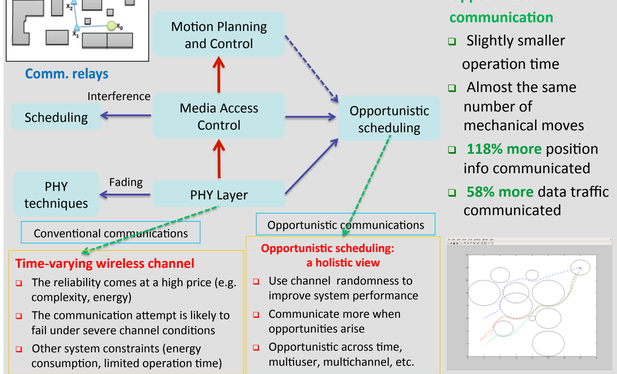
- The cognitive dialogue
- Dynamic attention mechanism
- Manipulation grammar
- Three-layer architecture

Social and Cognitive Robotics: Collaborative Autonomy





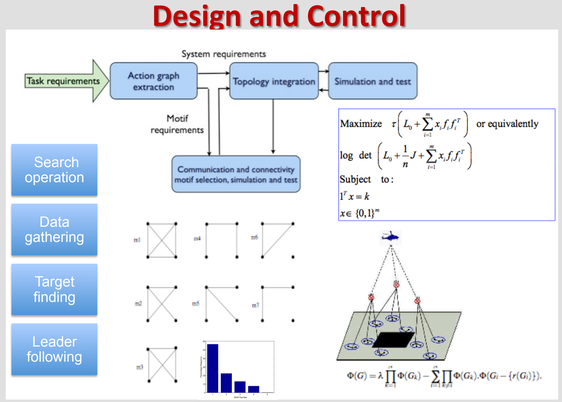
Opportunistic Communications and Planning



Opportunistic communication

- Slightly smaller operation time
- Almost the same number of mechanical moves
- **118% more** position info communicated
- **58% more** data traffic communicated

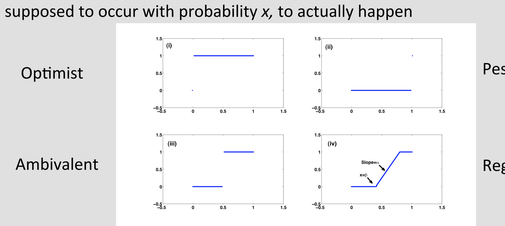
Systems Engineering Framework for Task Driven Communication Topology Design and Control



Behavior Learning for Collaboration

- A version of Cucker-Smale algorithm for "language acquisition"
- Behavior: A piecewise linear function $f : X = [0,1] \to Y = [0,1]$.

Given an r.v. x, f_i determines whether agent i expects an event that is supposed to occur with probability x, to actually happen

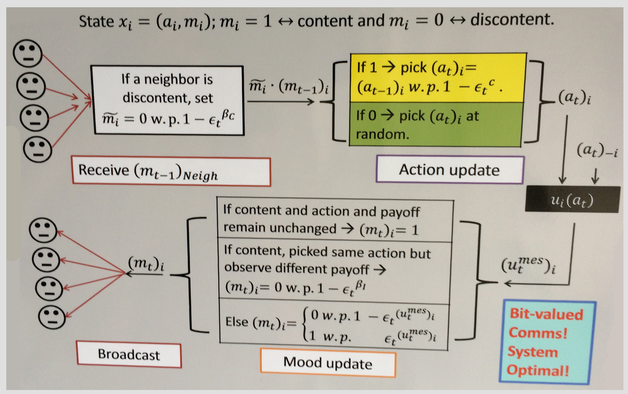


- Communicated data: $\{x_j(t), y_j(t) = f(x_j(t), \theta_1, \theta_2)\}_{j \in N(i)}$
- Update

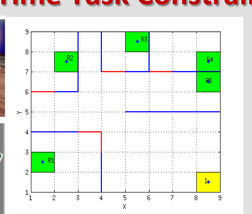
$$f(x_i(t+1)) = \arg\min_{f \in \mathcal{F}} \sum_{j \in N(i)} w_{ij} (f(x_j(t) - y_j(t))^2,$$

$$i = 1, 2, \ldots, n$$

Distributed Learning in Collaborative Control



Collaborative Planning and Re-planning with Finite-Time Task Constraints

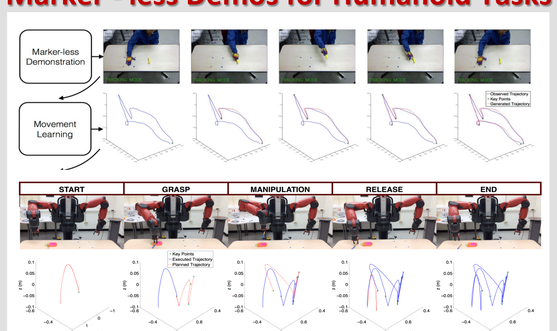


Starting from I, visit R3 within the time Interval I1, visit R4 within time interval I2; before visiting R3 or R4, robot must Visit R2 . Eventually visit R1 and R5, and Complete the whole task in least time.

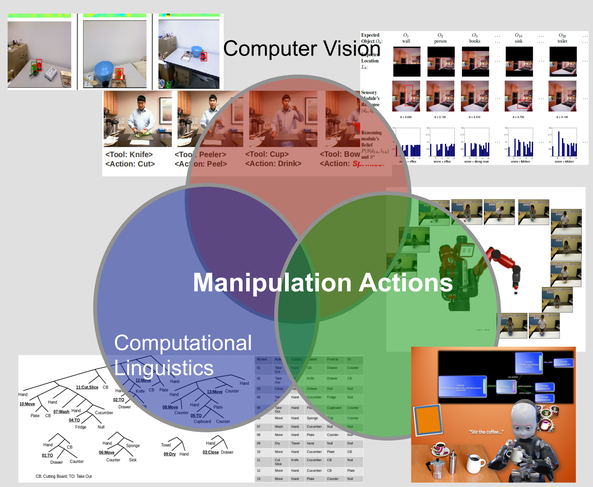
Multiple fires, diverse conditions Need to assess and plan/allocate

Resulting Continuous path In 3D space and time

Learning Hand Movements from Marker - less Demos for Humanoid Tasks

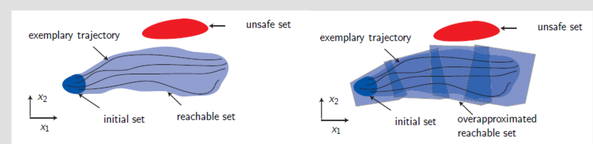


Baxter Experiment: Front view and 3D trajectory of generated movement for chopping task.



Safety & Trust in Human-Robot Teams : Integrating Logic and Set-valued Analytics

- **Space-time reachability analysis (now real time)**



- **Translate these to analytics: model checking, contracts, theorem proving, set valued -- Trust values? Metrics? Timed Languages?**
- **Roles? Role-based trust management?**

Sponsors: ARO, ARL, AFOSR, DARPA, NIST, NSF, SRC, Lockheed Martin, BAE

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