The Rational Selection of Goal Operations and the Integration of Search Strategies with Goal-Driven Autonomy

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Outline

- Intelligent Physical System
- Towards Intelligent Autonomy
- The Problem Domain
- Search Strategies
- Working Example
- Empirical Results
- Conclusion

Intelligent Physical System

A **Cognitive System** that combines perception, actuation, and communication to operate *robustly* in the real world

- **Capabilities:**
  - Perceive: Gather information about the real world.
  - Think: Process the percepts to achieve and generate thoughts/goals.
  - Act: Perform actions in the real-world using controls.
  - Communicate: Explain thought process to other agents.
- **Issues:**
  - Unexpected events
  - Partial Observability
- **Examples:**
  - Self-driving cars
  - Humanoid robots.

- **Simon**

- **Waymo**

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Towards Intelligent Autonomy

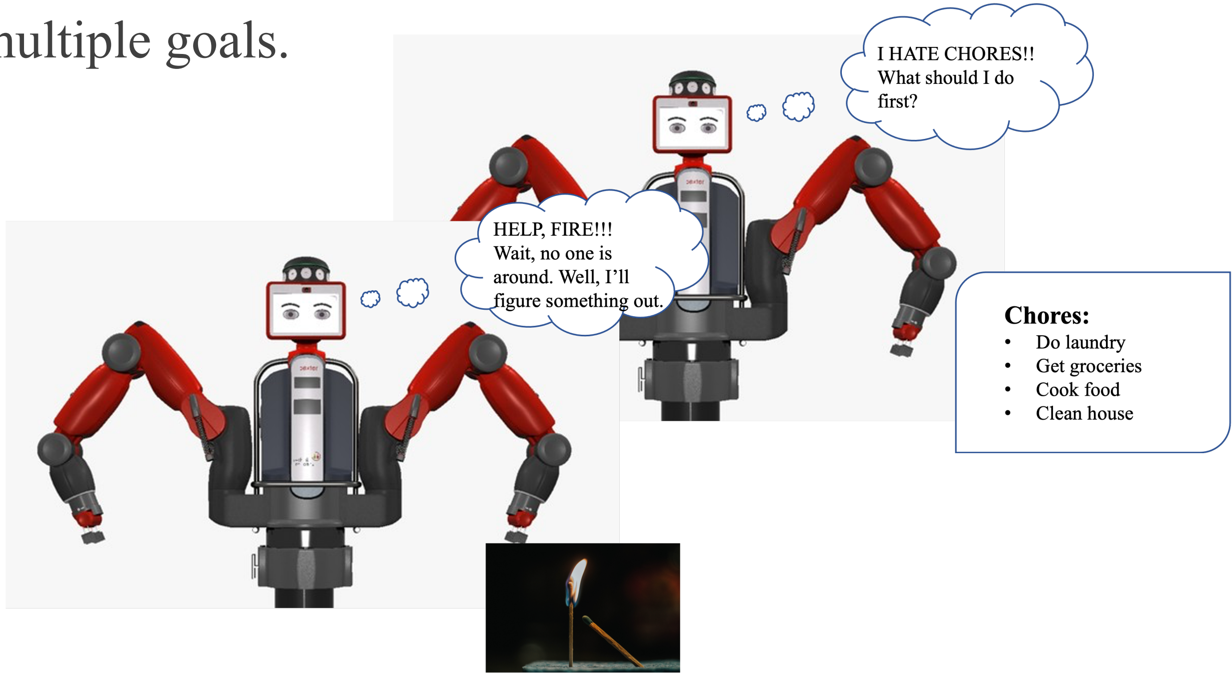
A Framework Focused on Reasoning about Agents' Goals.

Multi layer Approach to IPS.

- CDA: Ground Level
- Beliefs: Generate Predicates
- GDA: Goal Reasoning

Goal Operations

- Goal Selection: Select one appropriate goal among multiple goals.
- Goal Formulation: Create a new goal.
- Goal Change: Change goal to a similar one.
- Goal Monitors: Check if the goal is valid.
- Goal Delegation: Give goals to a different agent.



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- **Kondrakunta, S.,** Gogineni, V. R., Molineaux, M., & Cox, M. T. (In Press). Problem recognition, explanation and goal formulation. In *Fifth International Conference on Applied Cognitive Computing (ACC)*. Springer.
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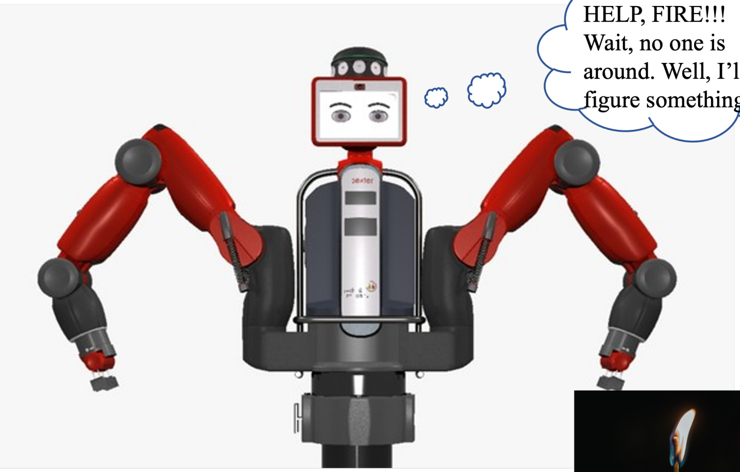
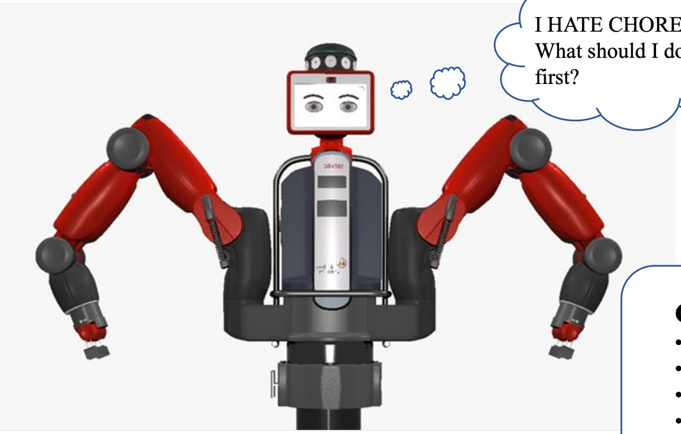
Multiple Goal Operations co-occur



- I am working on my chores, and a fire erupted nearby. Should I put the fire out (or) continue working on my chores?



Chores:
- Do laundry
- Get groceries
- Cook food
- Clean house

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The Rational Selection of Goal Operations

State Transition System: possible states and actions, successor function

$$\Sigma = (S, A, \gamma)$$

Successor Function: returns next state given current state and action

$$\gamma : S \times A \longrightarrow S$$

Problem Solution: a sequence of actions (plan)

$$\pi = \alpha_1 \mid \pi[2 \ldots n] = \langle \alpha_1, \alpha_2 \ldots \alpha_n \rangle$$

Plan Execution: starting from the initial state (s_0) results in the goal state (s_g)

$$\gamma(s_0, \pi) = \gamma(\gamma(s_0, \alpha_1), \pi[2 \ldots n]) \rightarrow s_g \vDash g$$

ExecGoalOperations $(\Sigma, s_c, s_e, g_c, \hat{G})$

$\pi \leftarrow \Pi(\Sigma, s_c, g_c)$
$\quad$ $while\ R(s_c) > 0\ do$
$\quad\quad$ $s_c \leftarrow \gamma(s_c, \pi[1])$
$\quad\quad$ $\pi \leftarrow \langle \alpha_2, \alpha_3, \ldots \alpha_n \rangle$
$\quad\quad$ $s_e \leftarrow s_e \cup pre(\pi[1]) \cup \pi[1]^+ - \pi[1]^-$
$\quad\quad$ $if\ s_c \nvDash s_e\ then$
$\quad\quad\quad$ $g_f \leftarrow \beta(s_c, g_c)$
$\quad\quad\quad$ $g_s \leftarrow \delta^{s_e}(s_c, \hat{G})$
$\quad\quad\quad$ $g_{aff} \leftarrow AllGoalsAffected(s_c, s_e, \hat{G})$
$\quad\quad\quad$ $if\ g_s\ in\ g_{aff}\ then$
$\quad\quad\quad\quad$ $g_c \leftarrow g_f$
$\quad\quad\quad\quad$ $\hat{G} \leftarrow \hat{G} \cup g_c$
$\quad\quad\quad$ $else$
$\quad\quad\quad\quad$ $g_c \leftarrow g_s$
$\quad\quad\quad$ $\pi \leftarrow \Pi(\Sigma, s_c, g_c)$
$\quad\quad$ $if\ \pi = \langle\rangle$ then
$\quad\quad\quad$ $\hat{G} \leftarrow \hat{G} - g_c$
$\quad\quad\quad$ $g_c \leftarrow \delta^{s_e}(s_c, \hat{G})$
$\quad\quad\quad$ $\pi \leftarrow Plan(\Sigma, s_c, g_c)$

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The Problem Domain

The Marine Survey Domain.

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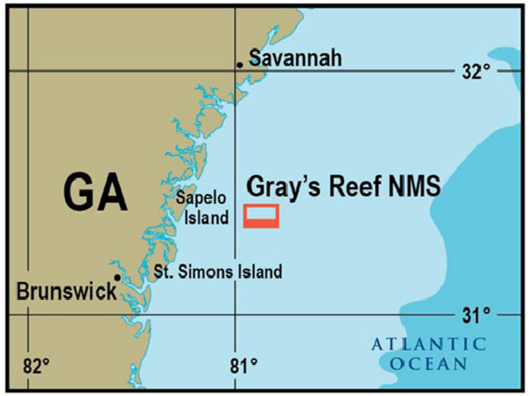


Sanctuary Coordinates

Southwest: 31°21.764'N (31.362732°N)
80°55.272'W (80.921200°W)

Northwest: 31°25.264'N (31.421064°N)
80°55.272'W (80.921200°W)

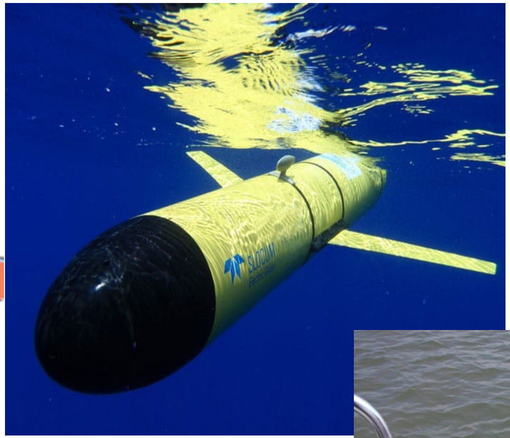
Northeast: 31°25.264'N (31.421064°N)
80°49.689'W (80.828145°W)

Southeast: 31°21.764'N (31.362732°N)
80°49.689'W (80.828145°W)

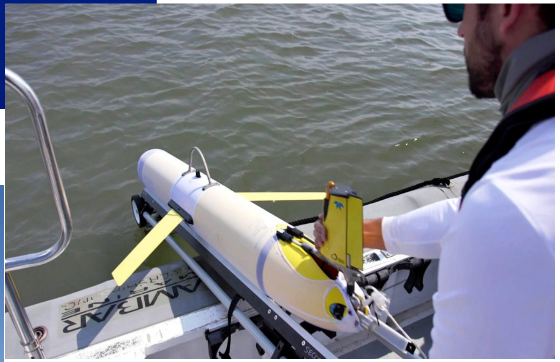
- Long missions (one - two months)
- Minimum communication

Autonomous Agents Used in the Domains

- Custom Robotic Fish



- Slocum Gliders



- Research Vessel

Goals and Problems

GOALS

- **Gather measurements**
  - Temperature
  - Salinity
  - Pressure
- **Discover hot spots**
- **Track fish**

PROBLEMS

- **Remora attacks**
- **Blowouts**
- **Obstacles**
- **Shark attacks**

Search Strategies

- **Structured Search (SS)**
  - Modified stochastic hill-climbing
  - Sample N-S-E-W sides of cell for estimate of adjacent cell densities
- **Ergodic Search (EG)**
  - Relates time-averaged trajectory to spatial distribution of information

$$\epsilon(x(\cdot)) = \sum_{k=0}^{K} \Delta_k |c_k(x(\cdot)) - \phi_k|^2$$

  - Simulate forward over limited horizon to produce control signal for trajectory
- **Structured Search Combined with Ergodic Search (SSCEG)**
  - Ergodic search with each cell of structure search
  - Ignores N-S-E-W edges

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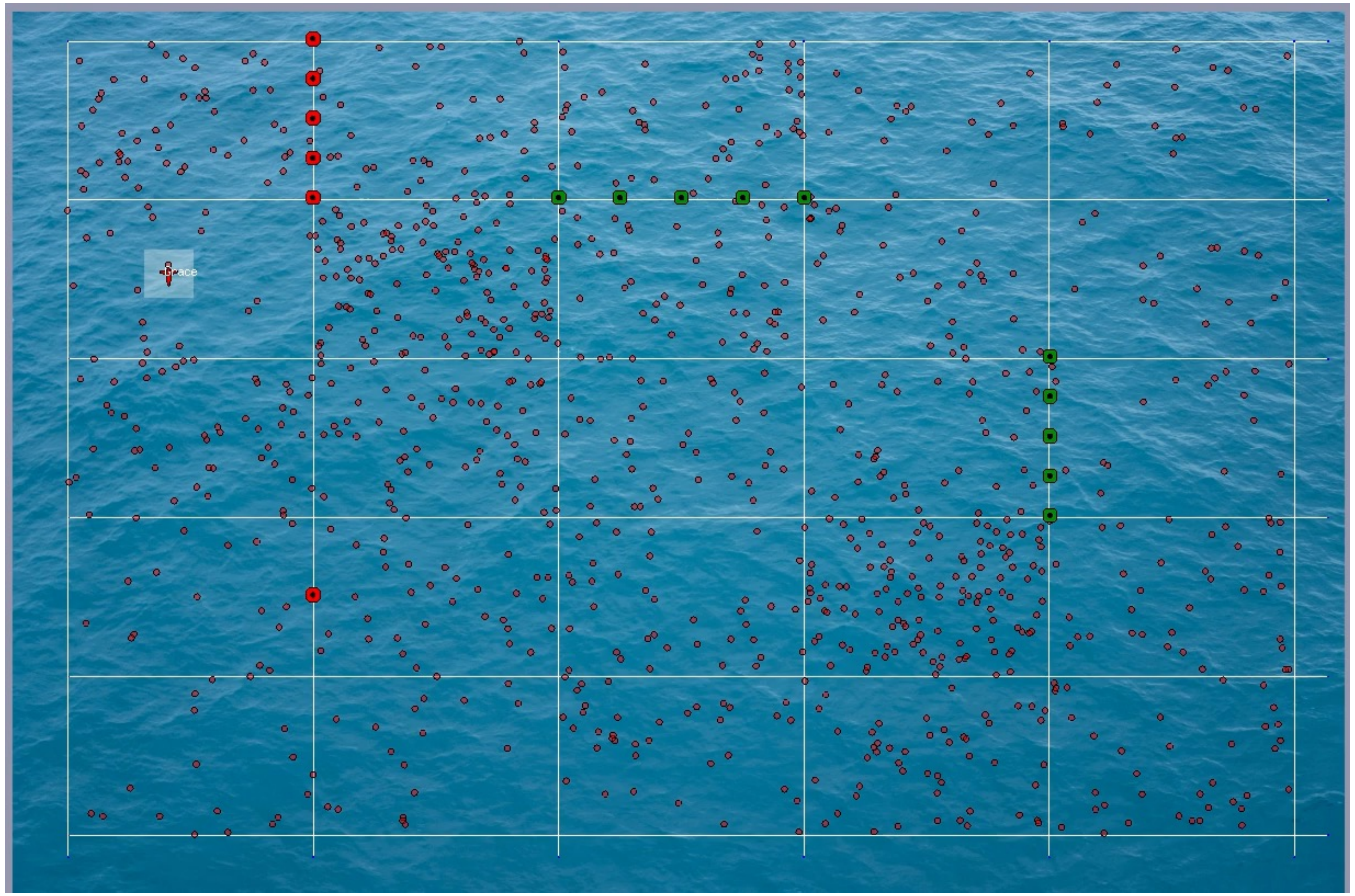
Working Example with Grace

- Mission Oriented Operating Suite (MOOS)
- Sensors on board:
  - Temperature
  - Pressure
  - Acoustic receiver
  - Several others
- Ping Detection:
  - Gaussian curve



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Experimental Setup

- Assumption: 1000 Fish tags
- Grace begins surveying with 100 initial starting locations and 25 cells, we have 100*25= 2500 trials.
- Anomalies: Remora attacks, blockades and flow.
- Performance metric: F1 Scores.
- Agents for comparison:
  - Select-1st: always chooses selection first
  - Formulate-1st: always chooses formulation first
  - ASGO: Uses the developed algorithm

Empirical Results

Anomalies	Parameter	Select-1st	Formulate-1st	ASGO
Remora and flow	Accuracy	0.984	0.983	0.993
	Recall	0.620	0.670	0.840
	Precision	0.984	0.893	0.988
	F1 score	**0.760**	**0.766**	**0.908**
Remora, block and flow	Accuracy	0.981	0.984	0.990
	Recall	0.540	0.650	0.790
	Precision	0.981	0.928	0.975
	F1 score	**0.697**	**0.765**	**0.872**

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Conclusion

- **Open-source Code available at** https://github.com/COLAB2/midca
- **Integrating cognition and autonomous control is hard in any domain**
  - Much still in preliminary stages, but exciting results are emerging
  - Combining simulation studies and fielded trial promises advances in intelligent autonomous agents
  - Work on belief spaces will better integrate Cognitive agents and Control architectures.
  - Include other goal operations, Ex: goal change.