Multi-agent Goal Delegation

Presented by

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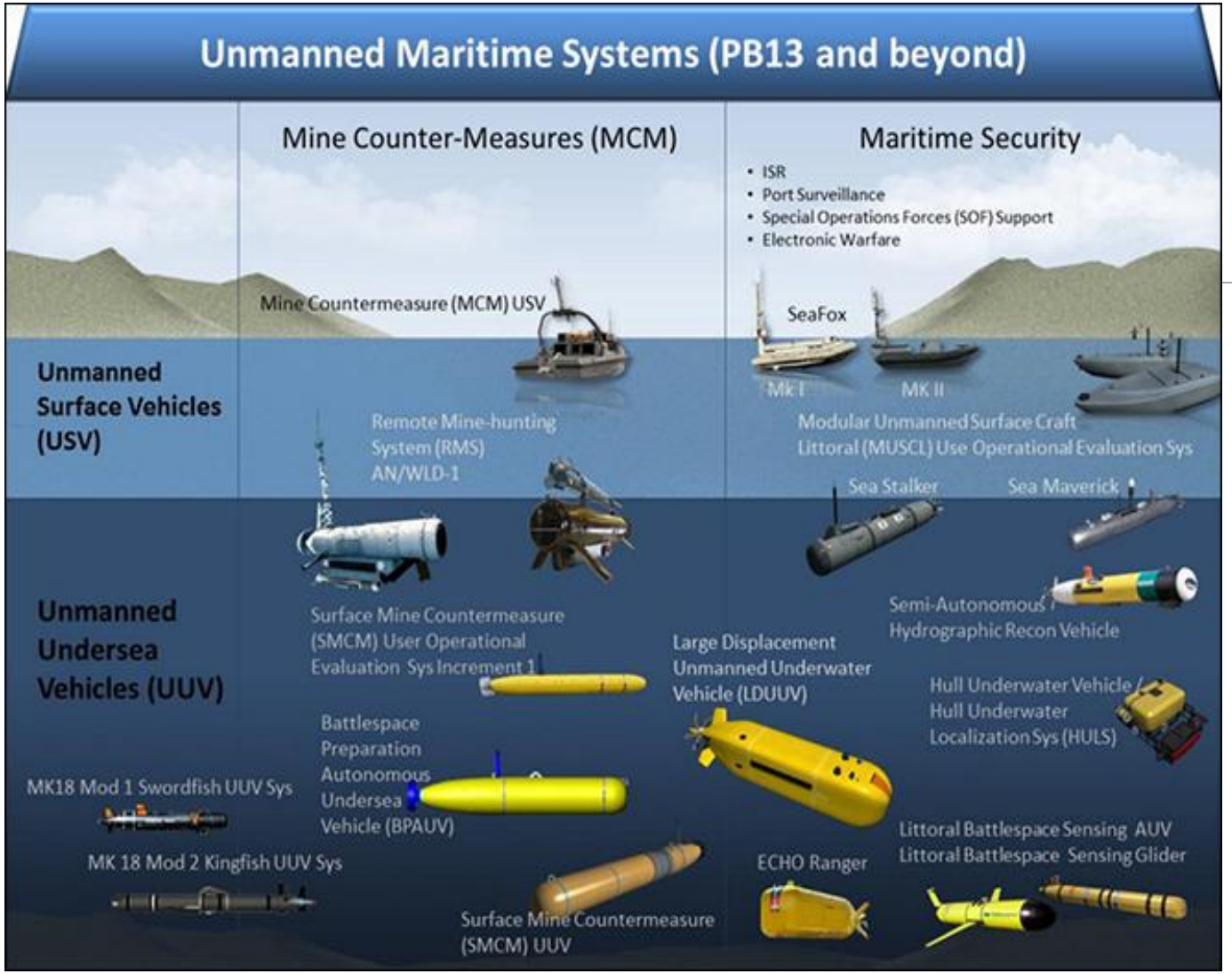

Figure 1: Classifications of Unmanned Maritime Systems (Photo: U.S. Department of Defense)[1]

Motivation

- **Multiple decentralized agents coordinate to achieve their goals**
- Why is goal delegation needed?
  - Limited available resources
  - Partial observability
- What should the agents delegate?
  - Goals
  - Knowledge about the goals
  - Motivation behind goals
- How should they coordinate?
  - Receiving agents should understand and pursue the goals

[1] *Unmanned Systems Integrated Roadmap FY 2013-2038*, Department of Defense – United States of America, 2013.

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Research Questions

- **How can a set of agents manage individual and shared goals in a dynamic world?**
  - What goals should an agent delegate?
  - Who should an agent delegate its goals to?
  - What required knowledge/goals should an agent share with other agents? and
  - How does the receiving agent decide about the delegated goals?

- **Assumptions:**
  - All the agents in a multi-agent environment are honest.
  - All the agents are distributed in nature.
  - All the agents have a standard communication framework (e.g., KQML) to communicate.

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Outline

- Detection of Goal Delegation
- Agent Selection
- Knowledge Sharing
- Goal Acceptance / Rejection
- Experimental Setup
- Conclusion and Future Research

Detection of Goal Delegation

- An agent delegates its goals when it is expected to run out of resources $\neg(agent_j \Longrightarrow \hat{G}_j)$ then δ_j^{de}

DetectDelegation $(\hat{G}_c, s_{cc})$

$g_{achievable} \leftarrow \emptyset$

$\hat{r} \leftarrow \hat{R}(\hat{G}_c, s_{cc})$ *// Estimation of agent's resources*

while $\hat{r} > 0$ *do* *// Loop until the agent has enough resources*

$g_s \leftarrow \underset{g \in (\hat{G}_i - g_{achievable})}{argmax} \hat{P}(g, s_{cc})$ *// Select goals with maximum priority*

// From the goals with the same priority,

$g_s \leftarrow \underset{g \in g_s}{argmin} \hat{R}(g, s_{ci})$ *select goals with minimum resources*

$\hat{r} \leftarrow \hat{r} - \hat{R}(g_s, s_{cc})$ *// Estimate the remaining resources*

$g_{achievable} \leftarrow g_{achievable} \cup g_s$ *// Add selected goals to agent's achievable goals*

if $(\hat{G}_c - g_{achievable})$ *is* $\emptyset$ *then* *// Break, if agent can achieve all its goals*

break

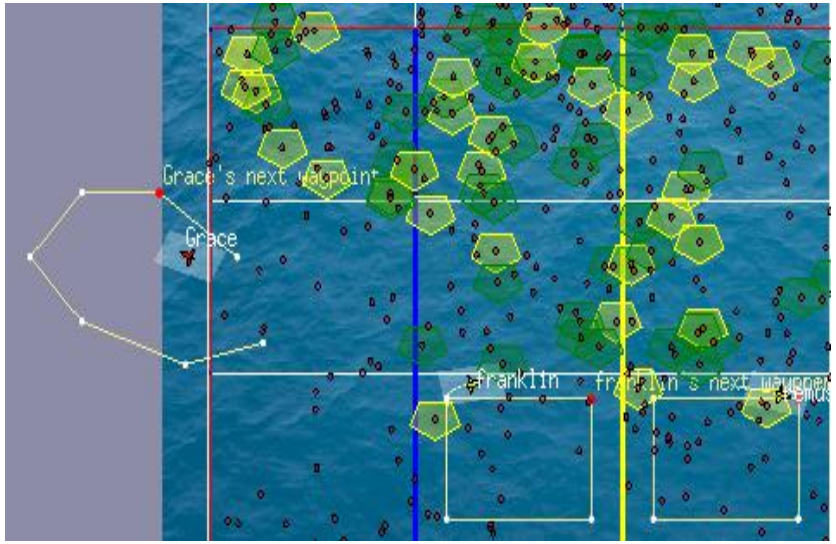
$g_d \leftarrow (\hat{G}_c - g_{achievable})$ *// Goals agent cannot achieve*

return g_d *// Return delegated goals*

Agent Selection

- $\neg(agent_c \Longrightarrow \hat{G}_j)$ then $\delta_j^{de}(\{agent_1 \ldots agent_k\} - \{agent_c\}, \hat{G}_j) \rightarrow (agent_i, g_d)$

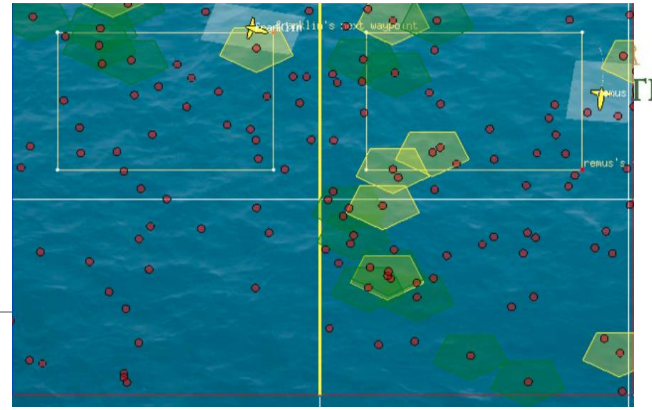
- How to choose $agent_i$?
  - Obtain landmarks $L\langle 1 \ldots m \rangle$ for g_d
  - $agent_i = \underset{(j \in \{agent_1 \ldots agent_k\} - \{agent_c\})}{arg\min} (cost(\hat{\pi}(\Sigma_j, s_{cj}, L_1))$



- Given a planning task $((S_j, A_j, \gamma_j), s_{cj}, g_{cj})$. A fact L is a landmark is for all $\pi_j = \langle \alpha_1, \alpha_2, \ldots \alpha_n \rangle \in A^*, g_{cj} \subseteq Result(s_{cj}, \pi_j)$: $L \in Result(s_{cj}, \langle \alpha_1, \alpha_2, \ldots \alpha_i \rangle)$ for some $0 \leq i \leq n$. [1]

I. . Hoffmann, J., Porteous, J., & Sebastia, L. (2004). Ordered landmarks in planning. *Journal of Artificial Intelligence Research*, *22*, 215-278

Knowledge sharing between agents



- What knowledge does $agent_c$ share with $agent_i$?
  - From the perspective of $agent_c$:

    What information does $agent_c$ know that $agent_i$ lacks related to the delegated goal? (Theory of Mind)

KnowledgeSharing $(\Sigma_i, s_{ci}, s_{cc}, L[1])$

$\langle a_1, a_2, ...a_n \rangle \leftarrow \hat{\Pi}(\Sigma_i, s_{ci}, L[1])$ // *Estimated actions to achieve first Landmark*

$s_{share} \leftarrow \emptyset$ // *Knowledge states to share with* $agent_i$

$s_{ei} \leftarrow \emptyset$ // *The expected states of* $agent_i$

for a *in* $\langle a_1, a_2, ...a_n \rangle$

$s_{ei} \leftarrow s_{ei} \cup pre(a) \cup a^+ - a^-$ // *Expectations of* $agent_i$ *stemming from the results of action* a

$s_r \leftarrow AbstractRelatedStates(s_{ei}, s_{cc})$ // *Related states of* $agent_c$ *to expectations*

$s_{share} \leftarrow s_{share} \cup (s_r - s_{ci})$ // *Add related states to share with* $agent_i$

$s_{ci} \leftarrow s_{ci} \cup s_{share}$ // *Update knowledge of* $agent_i$

return s_{share}

Goal Accept/Reject

- How does $agent_i$ decide to accept or reject the delegated goals g_d?

GoalAcceptReject $(\hat{G}_i, s_{ci}, g_d)$ // *agent'is goal agenda, its current state and delegated goals*

$g_{unachievable} \leftarrow MonitorDelegation(\hat{G}_i \cup g_d, s_{ci})$ // *Obtain unachievable goals*

if $g_d \notin g_{unachievable}$ // *If delegated goals are achievable*

$\hat{G}_i \leftarrow \hat{G}_i \cup g_d$ // *Add delegated goals to goal agenda*

return $\hat{G}_i$

Experimental Setup

- Agents :
  - Grace,
  - Franklin and
  - Remus

- Anomalies:
  - Remora Attacks
  - Heavy Flow at (0,2) and (2,0)

Evaluation : Types of Multi-agent Systems

Ideal: There are no anomalies, and each agent does their own goals (no need for delegation)

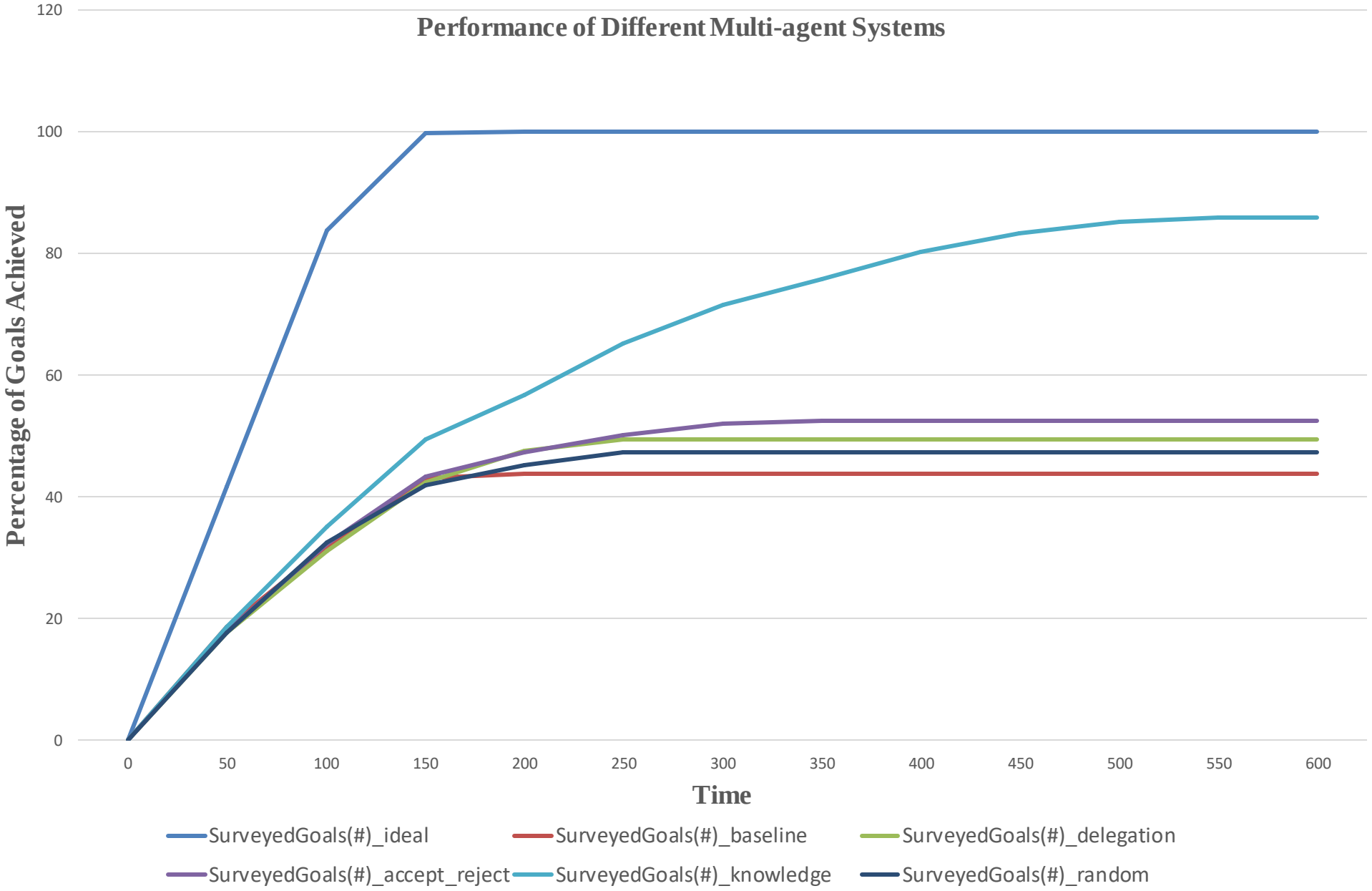
Baseline: There are remora attacks and blow out, but does not delegate

Goal Delegation (agent selection): There are remora attacks and blow out, delegates goals to a selected agent but the goals are always accepted

Random Goal Delegation (random agent selection): There are remora attacks and blow out, delegates goals to a selected agent but the goals are always accepted

Goal Delegation with accept/reject: There are remora attacks and blow out, delegates goals to a selected agent and accepts/rejects goals based on its situation

Goal Delegation with accept/reject and knowledge sharing: There are remora attacks and blow out, delegates goals to a selected agent, accepts/rejects goals, and shares required knowledge


Performance of Different Multi-agent Systems
Percentage of Goals Achieved
120
100
80
60
40
20
0
0
50
100
150
200
250
300
350
400
450
500
550
600
Time
SurveyedGoals(#)_ideal
SurveyedGoals(#)_baseline
SurveyedGoals(#)_delegation
SurveyedGoals(#)_accept_reject
SurveyedGoals(#)_knowledge
SurveyedGoals(#)_random

Conclusion & Future Research

- To Perform Goal Delegation, the delegating agent needs to
  - Detect Goal Delegation
  - Perform agent selection
  - Provide required knowledge and
  - Decide to Accept/Reject Goals.
- Explaining motivations behind the goals
- Usurpation
- Goals sharing using Hierarchal Goal Networks (HGN)