

Network-Aware Automated Planning and Plan Execution

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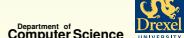
Motivation

April 2009:

- 75% of coalition force casualties in Afghanistan are from roadside bombs.
- 40% of coalition force casualties in Iraq are from roadside bombs.

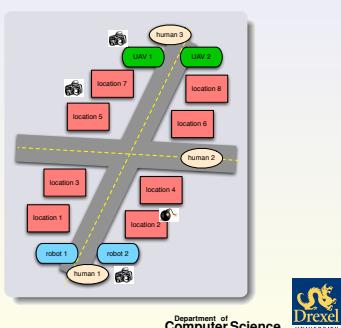


Source: Tom Vanden Brook, USA Today



Motivating Scenario

- IED Detection.
- Monitor Locations.
- Techniques.
- Actors.
- Resources.
- Evaluators.



Motivating Scenario

Heterogeneous Network

multiple different network technologies are combined to work together simultaneously.

Network-Centric System

a distributed system where performance is dependent on the quality of the underlying network communication links.



Notes

Contributions

- ➊ Qualitatively-different plans:
 - Generating plans over a range of evaluation criteria;
 - Visualizing plan evaluations.
 - Improve plan selection.
- ➋ Network-Aware Agents:
 - Classical planning domains for distributed service composition;
 - Measuring the performance and effectiveness of planning, execution, and monitoring agents;
 - Incorporating network-awareness.

Notes

Service Composition to Automated Planning

Definition

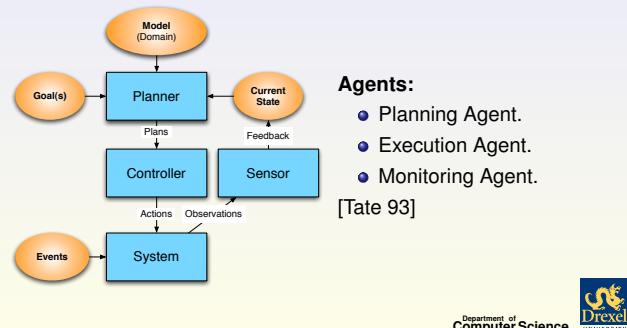
"Service composition is the linking... of existing services so that their aggregate behavior is that of a desired service (the goal)" [Hoffmann *et al.* 09].

- Requires Semantic Web Services [Sirin *et al.* 04].
- QoS Assurance [Gu *et al.* 03].

Assumes static networking.

Notes

Agents in Planning



Notes

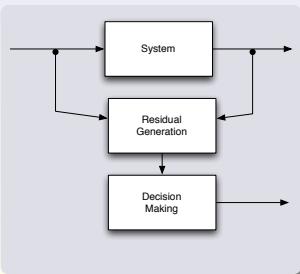
Planning Under Uncertainty

Restrictive Assumptions: Sources of Uncertainty:

- Determinism.
 - Full observability.
 - Reachability goals.
- [Nau *et al.* 04]
- Partial observability.
 - Unreliable resources.
 - Measurement variance.
 - Inherently vague concepts.

Notes

Fault Detection & Isolation (FDI)



Types of FDI:

- Analytic.
- Data-driven.
- Knowledge-based.

[Pettersson 05]

Notes

Approach

- ① Modify planner to improve the quality of the plans it produces based on evaluation criteria.
- ② Add network-awareness to planning, execution, and monitoring agents.

Purpose

To improve network-centric automated planning and execution.

Notes

Formal Problem Statement

Σ is the planning domain — the model of the world passed as input to the planner.

Σ is a Tuple

- S set of states;
- A set of actions;
- E set of events;
- γ transition function $\gamma : S \times A \rightarrow S$.

Notes

Formal Problem Statement

The functions on planning actions:

- For $a \in A$
- $\text{precond}(a)$ preconditions of a ;
 - $\text{effects}^+(a)$ positive effects of a ;
 - $\text{effects}^-(a)$ negative effects of a ;
 - $\text{host}(a)$ the single host h from a ;
 - $\text{resources}(a)$ the set of resources (parameters) of action a .

Notes

Domain-Independent Planning Agent

- Uses I-Plan's default strategy.

I-Plan

University of Edinburgh, Tate *et al.*'s plan-space HTN planner which is built on an intelligent agent framework, I-X.

Process

- ➊ Traverses search space depth-first.
- ➋ Encounter an alternative whose constraints cannot be satisfied.
- ➌ Backtracks using an A* search.

Notes

Random Planning Agent

- DFS with random branching.

Process

CONSTRUCTRANDOMPLAN(I_P)

```

1: toVisit.push( $s_0$ )
2: while  $\neg$ toVisit.empty()  $\wedge$   $\neg$ solution(toVisit.peek()) do
3:    $v \leftarrow$  toVisit.pop()
4:   if  $v \notin$  visited then
5:     visited.add( $v$ )
6:      $r \leftarrow$  randomize( $v$ .children())
7:     toVisit.push( $r$ )
8:   end if
9: end while
10: return toVisit.peek()

```

Notes

Guided Planning Agent

Generates qualitatively-different plans over:

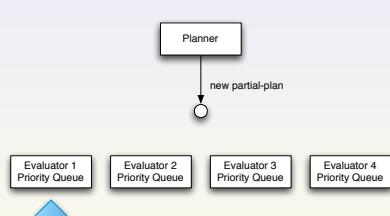
- Domain-dependent criteria, and
- Network-centric criteria.

Process

- ➊ A priority queue exists for each evaluator.
- ➋ Every partial-plan is evaluated by all evaluators and placed in their respective priority queues.
- ➌ The partial-plan at the head of each priority queue is used for the next step.

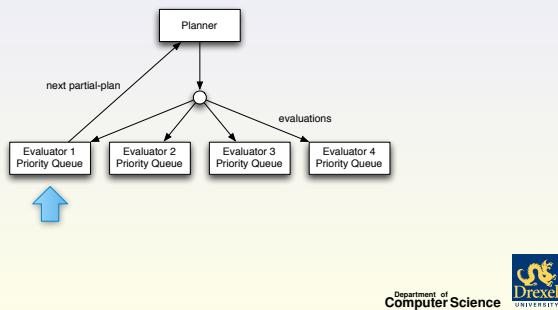
Notes

Guided Planning Agent



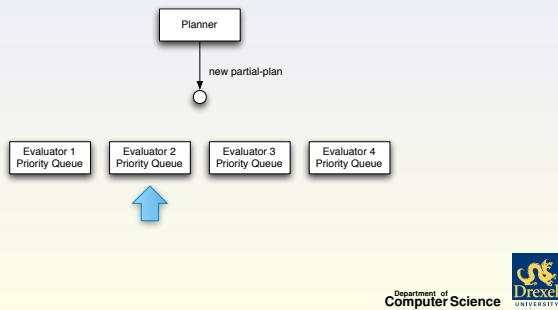
Notes

Guided Planning Agent



Notes

Guided Planning Agent



Notes

Execution Agents



Agent types:

- Naïve.
- Reactive.
- Proactive.

Defined by:

- Service invocation.
- Error handling.

Notes

Naïve Execution Agent

Naïve Execution Agent Properties

Service Invocation Invokes services exactly as described by p_j .

The naïve agent requires that

$$\forall \text{ actions } a \in p_j, \text{host}(a) \neq \emptyset \wedge \text{resources}(a) \neq \{\}.$$

Error Handling Ignores execution errors.

- Not network-aware.

Notes

Reactive Execution Agent

Reactive Execution Agent Properties

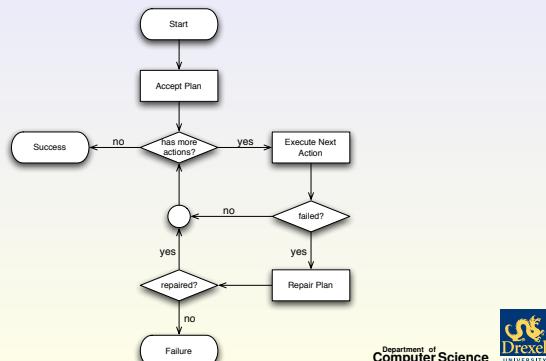
Service Invocation Invokes services exactly as described by p_I .
 The reactive agent requires that
 $\forall \text{actions } a \in p_I, \text{host}(a) \neq \emptyset \wedge \text{resources}(a) \neq \{\}$.

Error Handling Repairs the failed p_I by replacing failed service call(s) with new ones, creating p'_I .

- Network-aware recovery — plan repair.
- Uses routing protocol neighbors & link quality.

Notes

Reactive Execution Agent



Notes

Proactive Execution Agent

Proactive Execution Agent Properties

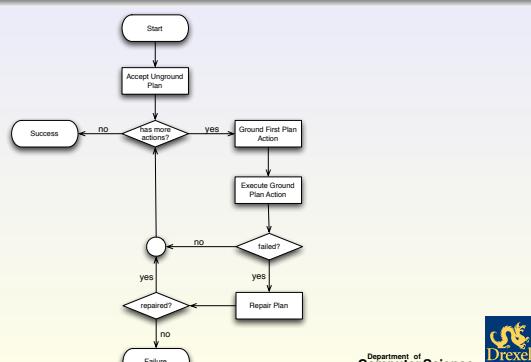
Service Invocation Invokes services using network-aware logic to choose the host and resources at execution time. The proactive execution agent uses only service descriptions from actions $a \in p_I$, meaning $\forall a \in p_I, \text{host}(a) = \emptyset \wedge \text{resources}(a) = \{\}$

Error Handling Repairs the failed p_I by replacing failed service call(s) with new ones, creating p'_I .

- Network-aware host/resource grounding.

Notes

Proactive Execution Agent



Notes

Monitoring Agents

Methods of FDI

- ① Analytic. ← Active Monitor
 - ② Data-driven. ← Passive Monitor
 - ③ Knowledge-based.



Analytic Monitoring Agent

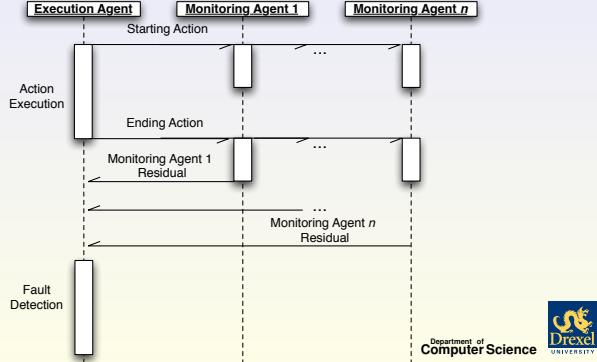
Given the ordered plan $p_I = \{a_0, a_1, \dots, a_{|p_I|}\}$

An analytic monitoring agent:

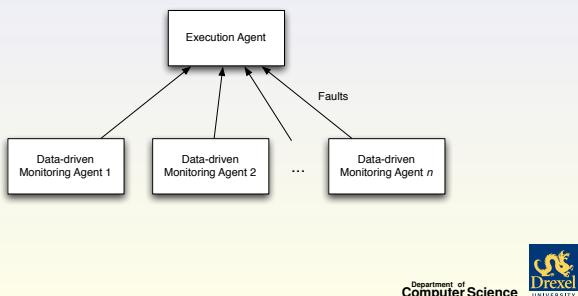
- ④ Constructs $p_M = \{m_0, m_1, \dots, m_{|p_I|+1}\}$, an ordered set of monitoring actions;
 - ⑤ Creates the new execution plan $p'_I = \bigcup_{i=0}^n \{m_i, a_i\}$;
 - ⑥ The result is $p'_I = \{m_0, a_0, m_1, a_1, \dots, m_{|p_I|}, a_{|p_I|}, m_{|p_I|+1}\}$.
 - ⑦ Each $m \in p_M$ calculates the residual between expected and actual bytes transferred.



Analytic Monitoring Agent



Data-driven Monitoring Agent



Notes



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Guided Plan

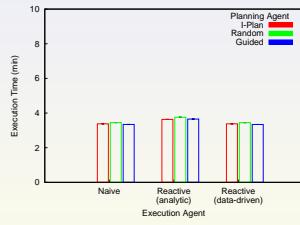
```

checkForIEDAt location1
photographicSearch node5 location1
physicalMoveToCamera node5 camera2
physicalMoveToCamera node5 location1 camera2
physicalMoveToCamera node5 location1 camera2
getOldPhoto node5 to photo-0
takePhoto node5 location1 camera2 to photo-1
comparePhotos node5 photo-1 photo-0
reportResults node5 location1
checkForIEDAt location2
manualSearch node3 location2
physicalMove node3 location2
conductScan node5 location2
reportResults node5 location2
checkForIEDAt location3
physicalMove node4 location3
physicalMove node4 location3
conductScan node4 location3
physicalMove node2 location3
reportResults node2 location3

```

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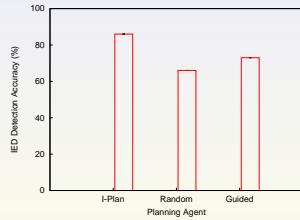
Local Results: Mean Time



- Network **not** a factor.
- Network-awareness did not hurt.

Notes

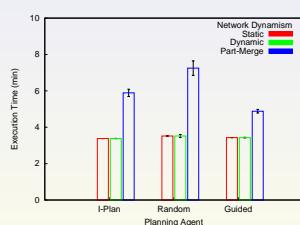
Local Results: Mean IED Detection Accuracy



- Ideal values of IED detection accuracy.

Notes

Planning Agent Comparison

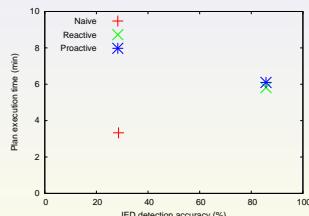


- Network disruptions adversely effect plan execution times.
- Guided was 16.7% faster than I-Plan and 28.8% faster than random in part-merge.

Notes

Execution Agent Effectiveness

Planning Agent: domain-independent (I-Plan default)



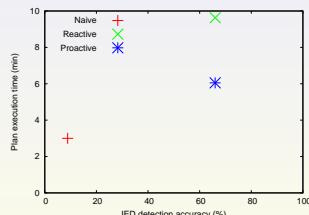
- Naïve agent has the lowest IED detection accuracy and exec. time.
- Reactive and proactive agents achieved ideal IED detection accuracies.

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Execution Agent Effectiveness

Planning Agent: random



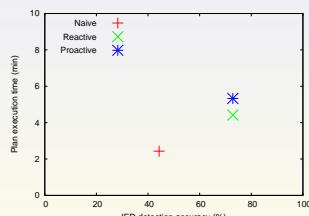
- Naïve agent failed most often.
- Proactive agent finished considerably faster than reactive.

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Execution Agent Effectiveness

Planning Agent: guided (network-aware)



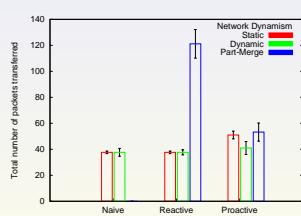
- Naïve agent failed most often.
- The guided algorithm advice significantly helped the execution agent.

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Execution Agent Performance

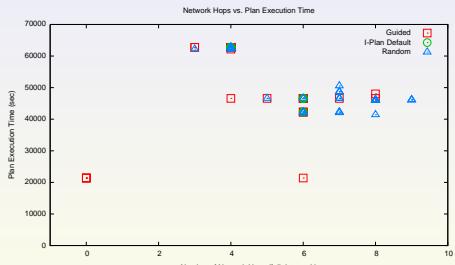
- Proactive agent uses slightly more network transmissions under connected mobility patterns.
- Under part-merge, the proactive agent sent fewer than half as many packets as the reactive agent.



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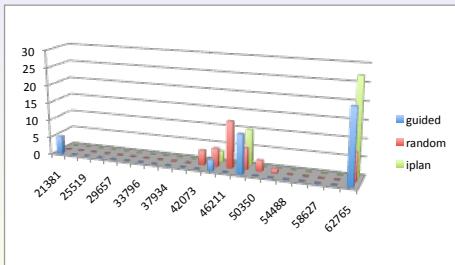
Network Hops and Execution Time



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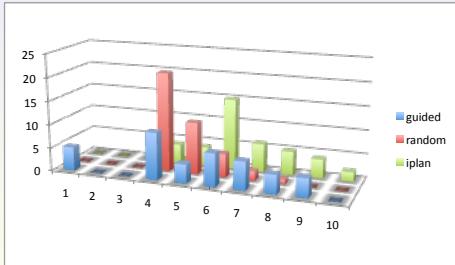
Plan Eval. Benchmarking Execution Time Distribution



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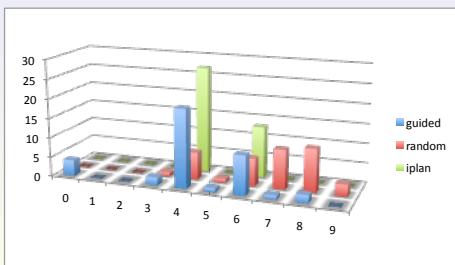
Plan Eval. Benchmarking IED Detect. Acc. Distribution



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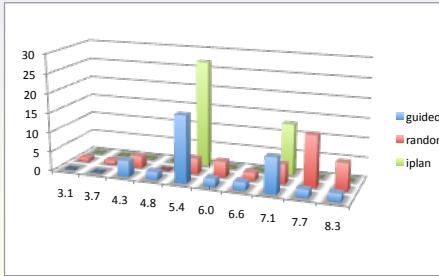
Plan Eval. Benchmarking Link Quality Distribution



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Plan Eval. Benchmarking Bandwidth Usage Distribution



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