A Model-Based System Supporting Automatic Self-Regeneration of Critical Software

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What we are trying to do

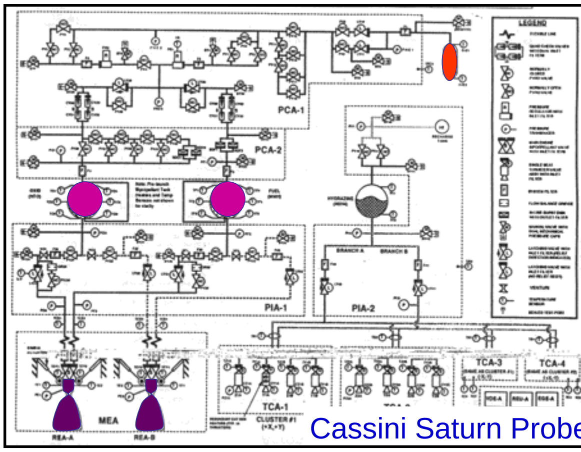
- Why software fails:
  - Software assumptions about the environment become invalid because of changes in the environment.
  - Software is attacked by a hostile agent.
  - Software changes introduce incompatibilities.
- What can be done when software fails:
  - Recognize that a failure has occurred.
  - Diagnose what has failed – and why.
  - Find an alternative way of achieving the intended behavior.

Runtime Models

Self repairing explorer: Deep Space 1

Flight Experiment, May 1999.

courtesy ARC & JPL



Cassini Saturn Probe

Project Status

Funding: DARPA (SRS), NASA (Ames)

Current State: Prototype System Operational

Project Premise:

Extend proven approach to hardware diagnosis and repair as used in DS-1 to critical software.

Principle Ideas:

Model-Based Language Approach

Redundant Methods

Method Deprecation

Model-Predictive Dispatch

Hierarchical Models

Adjustable Autonomy

Overview

Technical Objective:

When software fails because (a) environment changes (b) software incompatibility (c) hostile attack, (1) recognize that a failure has occurred, (2) diagnose what has failed and why, and (3) find an alternative way of achieving the intended behavior.

Technical approach:

By extending RMPL to support software failure, we can extend robustness in the face of hardware failures to robustness in the face of software failures. This involves:

(1) **Detection**
(2) **Diagnosis**
(3) **Reconfiguration**
(4) **Utility Maximization**.

RMPL Models of: Software Components, Component Hierarchy & Interconnectivity, and Correct Behavior.

Expected Benefits

- Software systems that can operate autonomously to achieve goals in complex and changing environments.
  - Modeling environment
- Software that detects and works around “bugs” resulting from incompatible software changes.
  - Modeling software components
- Software that detects and recovers from software attacks.
  - Modeling attack scenarios
- Software that automatically improves as better software components and models are added.

What can go wrong?

1. Hardware: A problem with robot hardware.
2. Software: A problem with the environment.
   1. A mismatch between a chosen algorithm and the environment such as there not being enough light to support processing of a color image.
   2. An unexpected imaging problem such as an obstruction to the visual field (caused by a large obscuring rock).

Solution to 2.1

Reconfigure the software structure:

1. Redundant Methods
2. Mode Estimation
3. Mode Reconfiguration

Solution to 2.2

Switch to a contingent plan:

1. Exception
2. Model Predictive Dispatch
3. Replanning

Test Bed Platform

Involves:

Cooperative use of multiple robots.

Timing critical software.

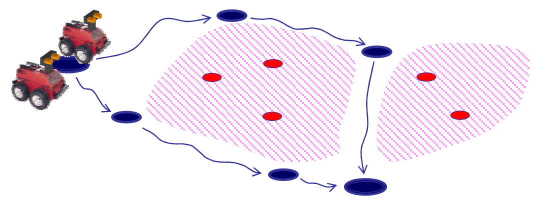
Reconfiguration of Software Components.

Multiple Redundant Methods

Continuous Replanning

Multiple Redundant Methods

Science Target Search Scenario



- Cooperatively search for targets in the predefined regions
- Search from predefined viewpoints
- Search for the targets using stereo cameras and various visualization algorithms

Science Target Search Scenario

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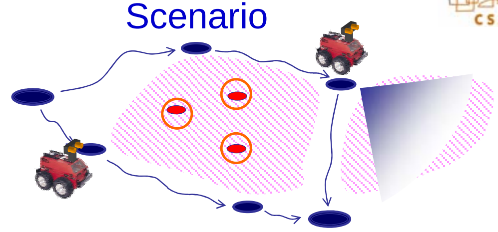
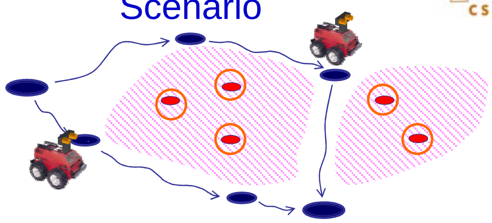
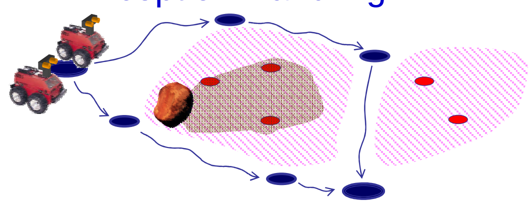


Science Target Search Scenario

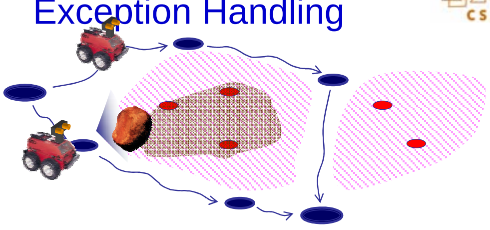


Method Regeneration: Exception Handling



- A rock blocks the view
  - Recover by taking the image from a different perspective (i.e. change the strategy)
- The shadow cast by the rock fails the imaging code from identifying the objects in view
  - Reconfigure the imaging algorithm to work under these conditions

Method Regeneration: Exception Handling



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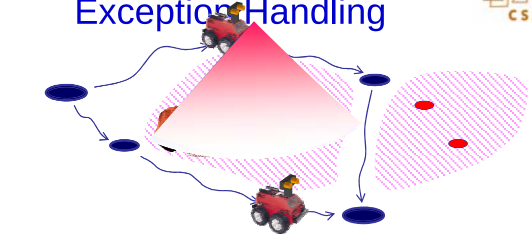

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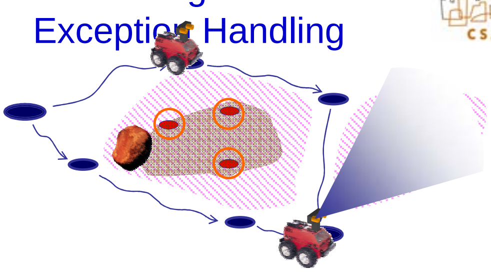

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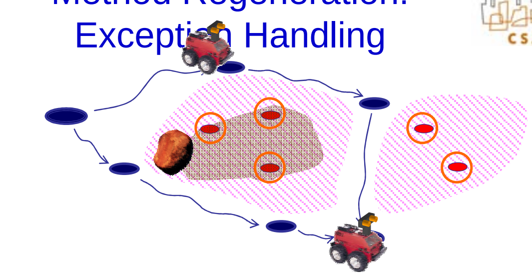
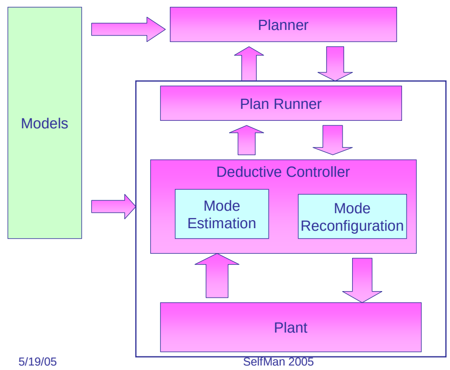
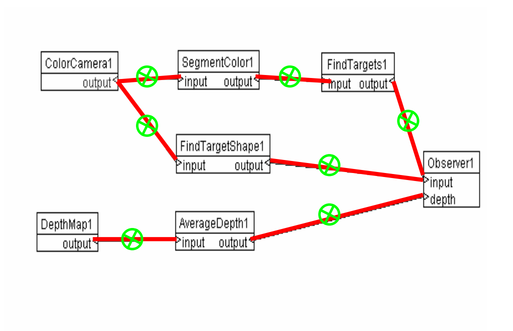


Overall Architecture

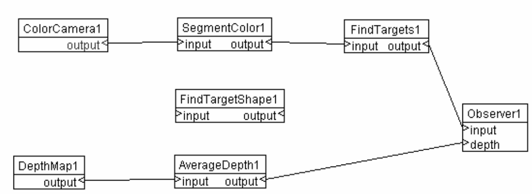


Reconfigurable Vision for Robust Rover Mapping

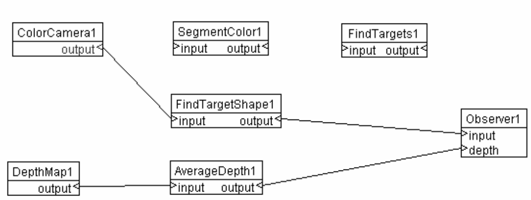
Reconfigurable Vision Plant Model



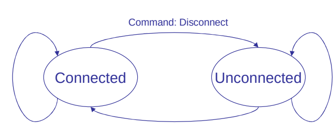
Nominal Configuration



Contingent Configuration



Connection



Inputs: x

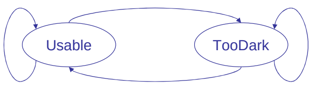
Outputs: x


```
class Connection ()
{
   RawImage image_in;
   SegmentedImage image_out;

   mode Connected (…) {
     primitive method disconnect () => Unconnected; }
   mode Unconnected (…) {
     primitive method connect () => Connected; }
  failure mode Failed (…) { … };
}
```

SegmentColor

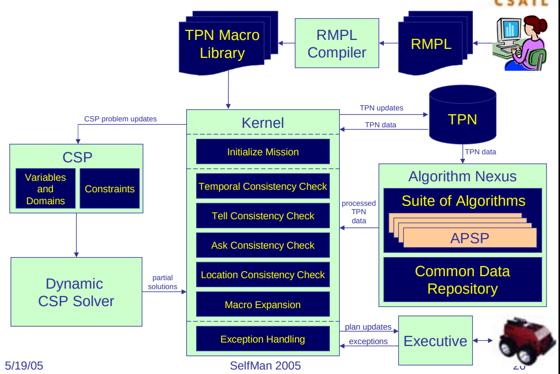
Inputs: RawImage

Outputs: SegmentedImage



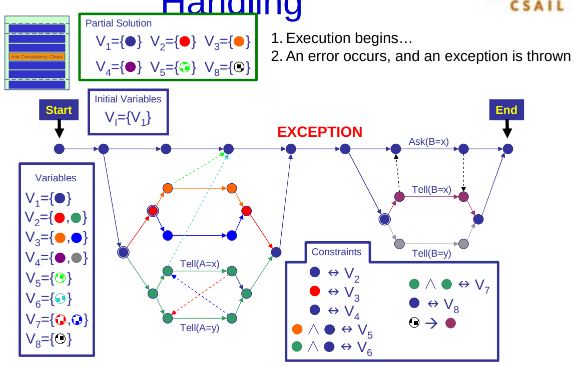

```
class SegmentColor ()
{
   RawImage image_in;
   SegmentedImage image_out;

   mode Usable ((image_in = Nominal)) { …   }

   mode TooDark ((image_in = Dark)) { … }
}
```


Block Diagram



Solution Analysis: Exception Handling

1. Execution begins…
2. An error occurs, and an exception is thrown



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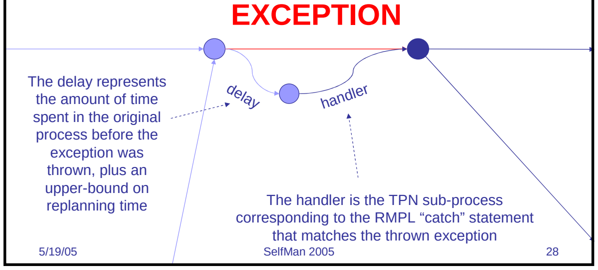
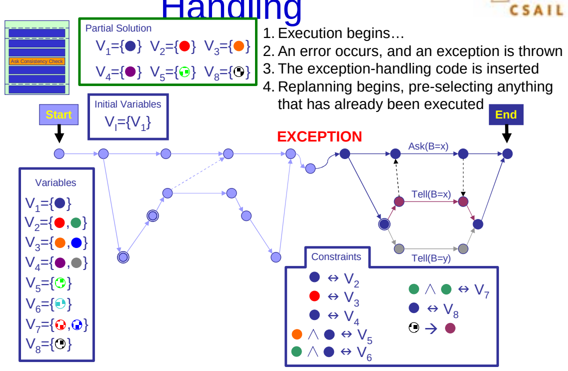


Solution Analysis: Exception Handling

1. Execution begins…
2. An error occurs, and an exception is thrown
3. The exception-handling code is inserted
4. Replanning begins, pre-selecting anything that has already been executed



Conclusions

- Models of correct operation permits:
  - Detection and Diagnosis of failed components.
  - Reconfiguration of Software/Hardware components to achieve high-level goals
  - Describe goals as abstract state trajectories.
- Software can be handled by adding:
  - Hierarchy to component organization
  - Models of the environment