# Adding Safeness to Dynamic Adaptation Techniques


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# RAPIDware Project

- Ongoing project in SENS Laboratory
- Funded by U.S Office of Naval Research
  - Critical Infrastructure Protection /Adaptable SW Program
- Goal: Software (middleware) that can protect itself from:
  - Hardware and software component failures
  - Changing environmental conditions
  - Changing requirements (e.g. security policies)
  - Malicious entities
- Applications:
  - Dynamic power management
  - Dynamic error correction for data transmission/receipt
  - Dynamically changing security algorithms and policies
  - Dynamic introduction of fault-tolerant capabilities

# Outline

- Dynamic adaptation
- Safe Adaptation
- Example Application

# Dynamic Adaptation

- At run time, adapt software in response to changes in:
  - environment, requirements, etc.
- Significant work in:
  - Adaptation mechanisms
  - Programming language extensions
  - Architectural description languages
- Correctness/Assurance Issues:
  - Adapted system provides correct functionality
  - Safeness: During adaptation process, no unexpected or undesirable results

# Key Concepts

**Assumptions:**

– A distributed system is modeled as a set of communicating components running on one or more processes**.**
– Adaptive actions: insert, remove, or replace SW elements

- **Atomic communication:**
  – An interaction, either within a component or between components, that cannot be interrupted.
  – Otherwise, it would potentially yield erroneous or unexpected results.

- **Dependency invariants**:
  – relationships among the components that should be held true throughout the program's execution.

**Safe adaptation process:**

- Does not interrupt atomic communications.
- Does not violate dependency invariants.

# Features

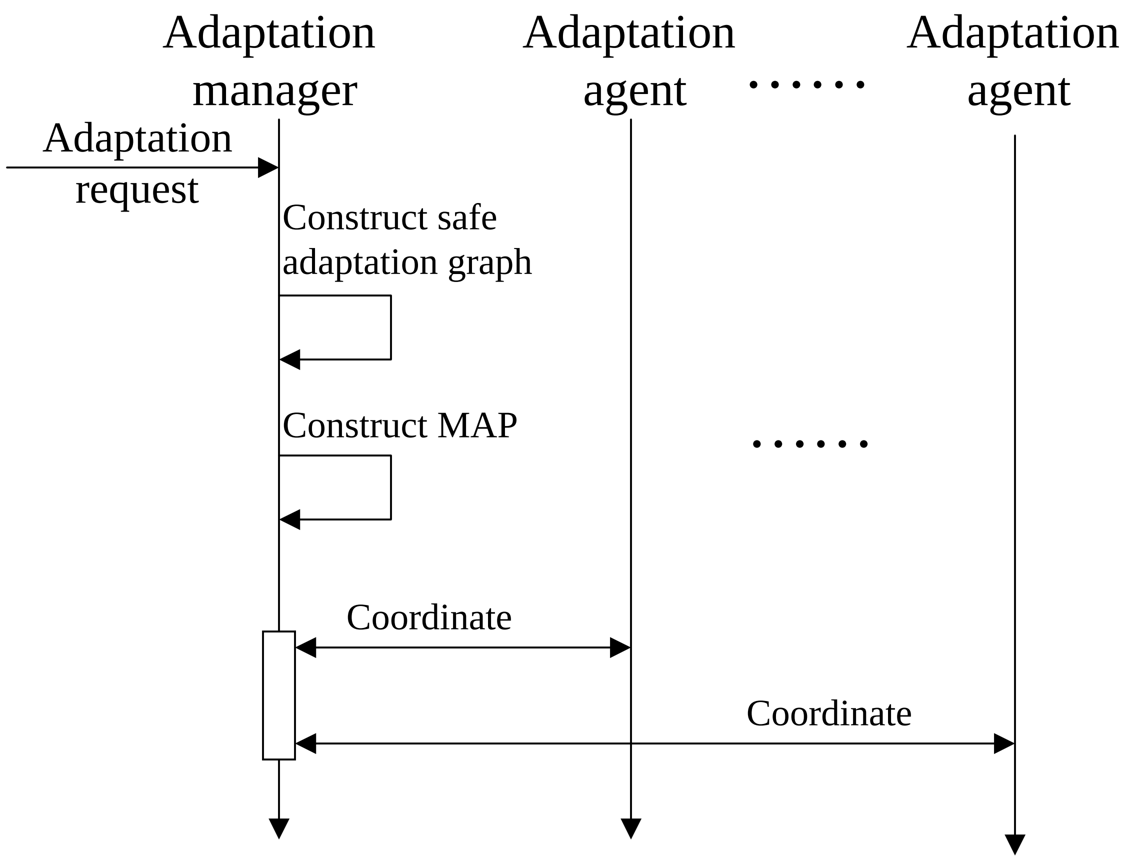
- Use dependency analysis to determine safe states for a given adaptive action
- Centralized management of adaptations,
  - Enable optimizations of adaptive actions
- Roll back mechanism when encounter failures during adaptation process

# Safe Adaptation Process

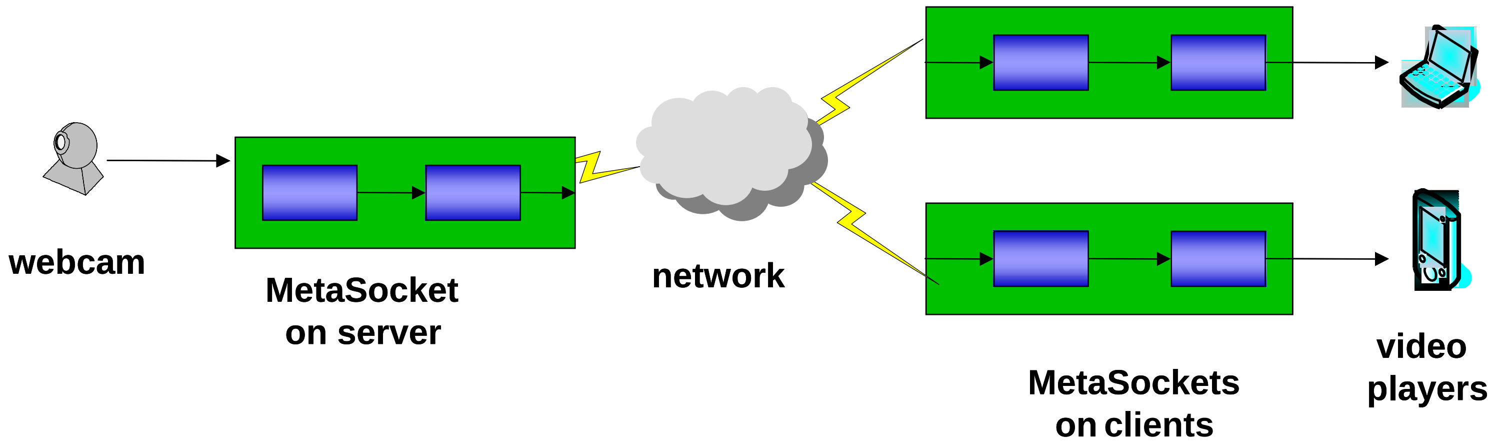
1. **Construct minimum adaptation path** (given a source and a target configurations)**.**
   (1) **Construct safe configuration set.**
   (2) **Construct safe adaptation graph:**
   vertices are safe configurations and arcs are adaptive actions.
   (3) **Assign a cost value to each arc.**
   (e.g. packet delay caused by the action)
   (1) **Search for minimum safe adaptation path (MAP**):
   path with minimum cost from the source to the target.

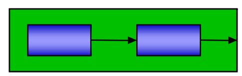
2. **Manage adaptation process.**
   - Components are reset to safe states before adaptation.
   - Blocking is introduced only when it is necessary to ensure safeness.
   - Adaptation process can roll back if encounter failure during process.

# Safe Adaptation Process



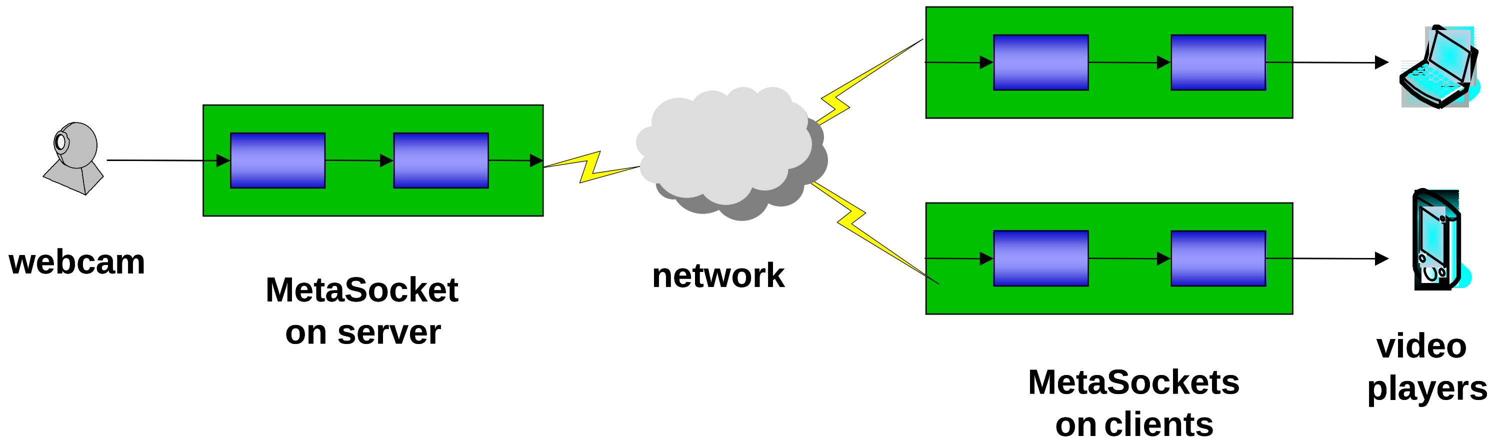
# Video Streaming Case Study




- MetaSocket [Sadjadi  et al]: 
  - chain of data stream filters and a Java socket
  - Alter behavior through filter insertion, removal, and replacement.

- **Video streaming example**
  - Video server: Sends data streams through a MetaSocket
    - A web camera captures video.
    - Video stream is sent to clients through a multicasting MetaSocket.
  - Video clients: Receive data streams through MetaSockets
    - A handheld computer.
    - A laptop computer.
  - Server and  clients are connected with wireless networks

# Video Streaming Case Study




## Filters available in the MetaSockets

**Server**
- E1: DES 64bit Encoder
- E2: DES 128bit Encoder

**Laptop Client**
- D4: DES 64bit Decoder
- D5: DES 128bit Decoder

**Hand-held Client**
- D1: DES 64bit Decoder
- D2: DES 64/128bit Decoder
- D3:DES 128bit Decoder

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# Video Streaming Case Study

- **Safe conditions:**
  - *Safe states*: System states in which, adaptive actions do not interrupt atomic communications.
    - Encoder: Not in the middle of encoding a packet.
    - Decoders: No in-flight packet for the decoders to be removed.
  - Dependency invariants:
    - Collaboration constraints: Each encoder requires the corresponding decoder.
    - Resource constraints: The hand-held device does not support two decoders simultaneously in the device.
    - Security constraints: All packets should be encoded with either 64-bit or 128-bit encoder.

# Video Streaming Case Study

- Adaptation goal:

  Reconfigure system

  – From: DES 64-bit encoder/decoders

  – To:  DES 128-bit encoder/decoders

  in order to "harden" security at run time

# Unsafe Adaptation Scenarios

- Interruption of atomic communication:
  - Replace the encoder while it is encoding a packet.
    - Effect: inconsistent results
  - Replace encoder and decoders simultaneously:
    - Effect: In-flight packets will not be decoded.
- Violation of dependency invariants:
  - First remove 64-bit DES encoder/decoders then insert 128-bit DES encoder/decoders:
    - Effect: Violates security constraints.
  - First insert 128-bit DES encoder, then insert 128-bit DES decoder:
    - Effect: Violates collaboration constraints.

# Video Streaming Case Study

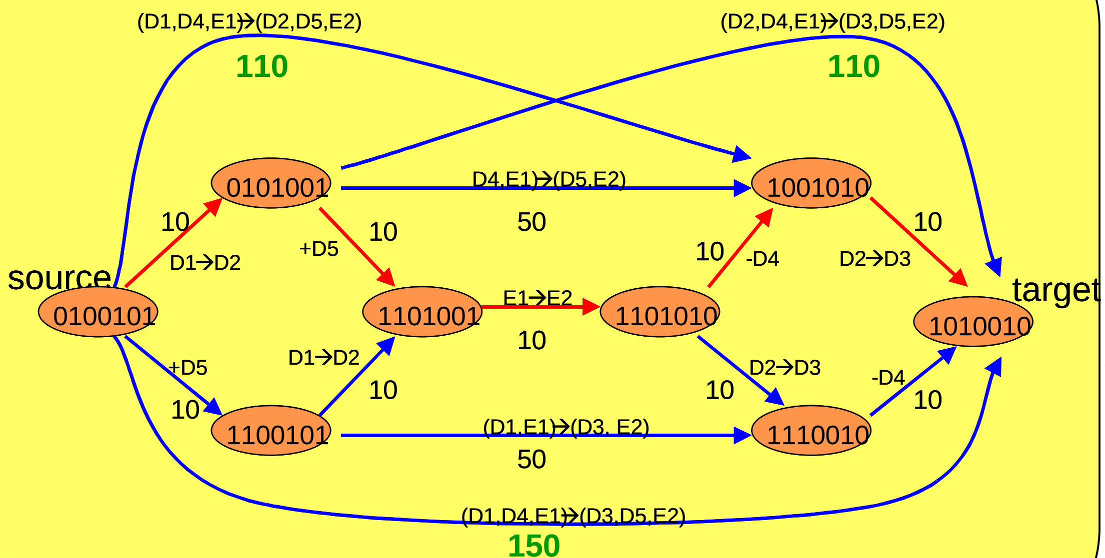


Figure 3 : Safe adaptation graph and MAP

- Use 7-bit vector to represent configuration: (D5,D4,D3,D2,D1,E2,E1)
- Vertices are safe configurations:
  - Source: (0100101)
  - Target: (1010010)
- Arcs are adaptive actions:
  - "+": insertion
  - "-": removal
  - "->": replacement
  - Numbers indicate costs
- MAP: red path identified by safe adaptation process
- Adaptive actions are performed in safe states of system.

# Conclusions

- Safeness
  - Adaptation process is safe with respect to:
    - not violating dependency invariants and
    - not interrupting atomic communications.
- Allows for choice and optimization among multiple safe adaptation paths
- Supports roll-back mechanism in case of failure during adaptation process
- Future work:
  - Investigating approximation algorithms for MAP
  - Cost measures for adaptive actions

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# Questions/Discussion


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# Related Work

- **Kramer and Magee: Conic and Darwin [1,2]**
  - Use *architectural description language* to model the system connection.
  - Separate communication from computation.
  - Dynamically connect or disconnect components.
  - Use *LTSA* to check adaptation models created with *FSP*.
- **Appavoo, and colleagues: Hot Swapping [3]**
  - *Quiescent* states are the states when it is safe to perform hot-swapping.
  - Use *generation counts* to determine quiescent states.
  - Component state transfer protocols are selected by *transfer negotiation protocol*.

# Related Work

- **Schlichting et al: Cactus [4]**
  - *Composite components* are composed of multiple *micro-components*.
  - The composite component can be reconfigured by altering its component micro-components.
  - It uses fuzzy logic to deal with change coordination.
  - It uses *graceful adaptation* process to perform adaptive actions.
- **Taylor, Medvidovic and et al: Chiron-2 and ArchStudio [5]**
  - C2 is layered ADL.
  - Substrate independent and implicit invocation facilitates dynamic insertion, removal, and replacement of components.
  - Systems can be reconfigured in three ways:
    - *Argo*: manipulates the model graphically.
    - *ArchShell*: Use command line to manipulate the system configuration
    - *Extension Wizard*: execute modification script on the end-user's system.

# Related Work

- Kulkarni et al [6]
  - safely composing distributed fault-tolerance components at run time.
  - use a spanning tree to pass adaptation messages.
  - uses a *reset* mechanism to block computations during the recomposition process.

# References


- [1] J. Kramer and J. Magee, "The evolving philosophers problem: Dynamic change management," *IEEE Trans. Softw. Eng*., vol. 16, no. 11, pp. 1293--1306, 1990.
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- [4] P. Bridges, etc, “Supporting coordinated adaptation in networked systems,‘” in *the 8th Workshop on Hot Topics in Operating Systems*, (Elmau, Germany), May 2001.
- [5] P. Oreizy, etc, “An architecture-based approach to self-adaptive software,” *IEEE Intelligent Systems*, 1999.
- [6] S. S. Kulkarni, etc, “Composing distributed fault-tolerance components,” in *Proccedings of the International Conference on Dependable Systems and Networks*, *Workshop on Principles of Dependable Systems,* 2003.

# Motivation

- **Dynamic adaptation is the trend:** software systems must adapt their behavior to changing conditions.
- **Examples warranting dynamic adaptations:**
  - Dynamic introductions of new strategies.
  - Quick responses to security threats.
  - Switching to certain execution mode to save battery life.
  - Insertions of encryption layers to network protocol stack.
- **Dynamic adaptation is prone to errors.**
  - Formalism: Unless adaptive software mechanisms are grounded in formalisms, the resulting systems will be prone to errant behavior.
  - Safe dynamic adaptation separates the safeness issue from the adaptation mechanism, and thus provides the basis for formal reasoning about the adaptation behavior.