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Author(s)	Schlichting, Rick
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Building Foundations for Dependable Systems

(Preliminary Version)

Rick Schlichting

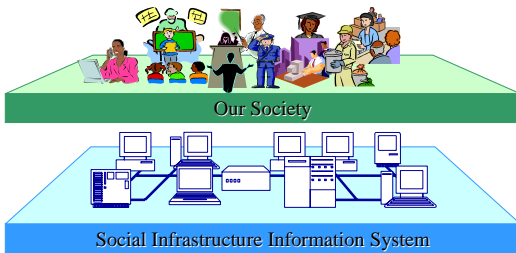
Software Systems Research Department
AT&T Labs-Research
Florham Park, NJ 07932, USA

Work done in collaboration with:

- Matti Hiltunen (AT&T)
- Former Arizona PhD student Jun He (Cisco).
- UIUC PhD student Kaustubh Joshi (AT&T VURI intern) and faculty member Bill Sanders.

Motivation

- Moving towards an e-society based on information systems and networks.



Next Generation Information Infrastructure

• Characteristics

- Multiple machines connected by networks.
- Spectrum of network types and technologies: wired, optical, wireless,
- Spectrum of distances: local-area, metro-area, wide-area,....
- Spectrum of devices: from sensors to mobile units to high end machines and clusters.
- Spectrum of applications.
- Dynamic execution conditions and resource demands.
- Multiple administrative domains.

➔ **MUST be dependable!**

Dependability

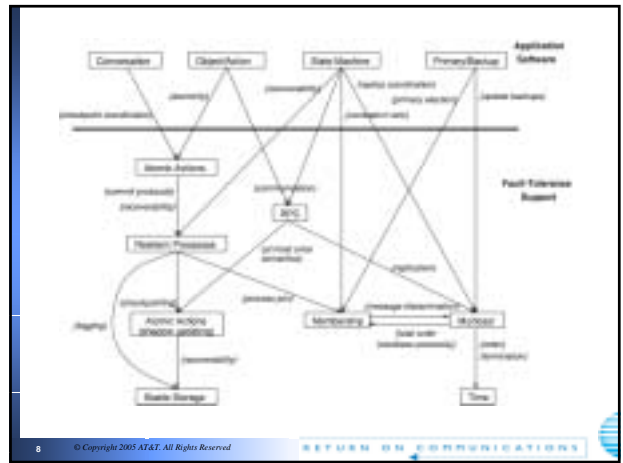
- **Definition:** The trustworthiness of a computing system such that reliance to be justifiably placed on the service it delivers.
(Laprie, et al., Dependability: Basic Concepts and Terminology, Springer-Verlag, 1992)
- Includes many properties and attributes.
 - Reliability
 - Availability
 - Safety
 - Security
 - Timeliness
- Non-functional or Quality of Service (QoS) attributes.
 - Focus is not on *how* something gets done, but rather *how well*.
- Immensely challenging to build software with these attributes!
 - Failures, intrusions....
 - Concurrent and non-deterministic execution
 - Heterogeneous systems and networks
 - Resource constraints
 - Multiple administrative domains
 - Scale
- Dealing with multiple attributes makes it even harder (*multidimensional QoS*).
- Fundamental issue is complexity.

System Abstractions

- *System abstractions* can simplify the process.
- **Definition:**
 - Simplified model of a real-life hardware/software component or function.
 - Extracts essential features while omitting unnecessary detail.
- **Goal: Building blocks for constructing more complex systems.**
- **Have long been used to as a way to simplify the design of complex systems.**
- **“Classic” examples:**
 - Process, file, virtual memory,....
 - Layered operating system architectures (e.g., THE system).
- ➔ **Good abstractions are those that people use without thinking about the underlying implementation.**

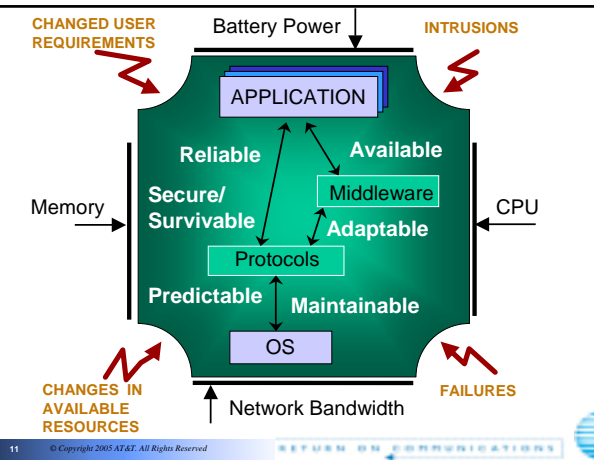
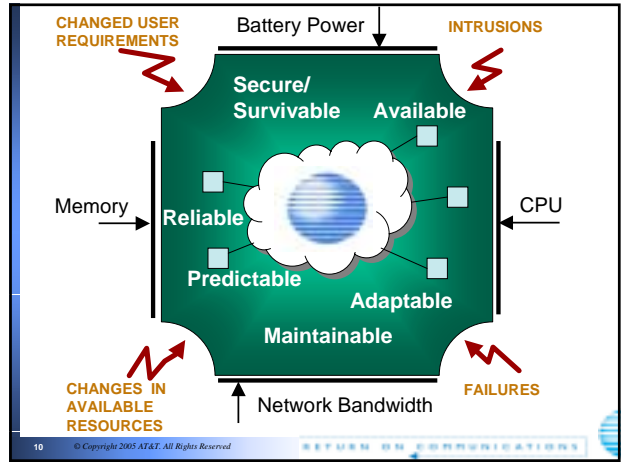
What about Dependability?

- **Certainly some good dependability-related abstractions.**
 - Provide enhanced QoS characteristics.
- **Hardware virtualization.**
 - Stable storage: abstract storage that never fails.
 - Fail-stop processor: virtual processor whose only failure is a detectable crash.
- **Services for networked systems.**
 - Often focus on providing common global information across machines despite machine and network failures (*virtual shared state*).
 - Implemented as middleware and/or using network protocols.
 - Consistent global clock: abstraction of a single system-wide clock.
 - Atomic multicast: shared message queue
 - Distributed atomic actions (transactions): all or nothing execution across machines.
- **Can also be organized as layers or hierarchies.**



Challenges and Issues

- **Abstraction failures (*leaky abstractions*).**
 - Impossible to implement an abstraction in which QoS properties hold under all conditions.
 - Inherently probabilistic.
- **Composing abstractions.**
 - Reasoning about properties of combinations of abstractions.
 - Conflicts and tradeoffs between different attributes.
 - Performance overhead.
- **Unnecessary attributes.**
 - Matching attributes of abstractions to application and execution environment.
 - Unnecessary attributes can mean extra execution overhead.
- **Changing QoS attributes dynamically.**
 - Providing ability to adapt at runtime



Dependable Systems Research at AT&T

Provide support for building system abstractions and services that bridge the gap between network and application.

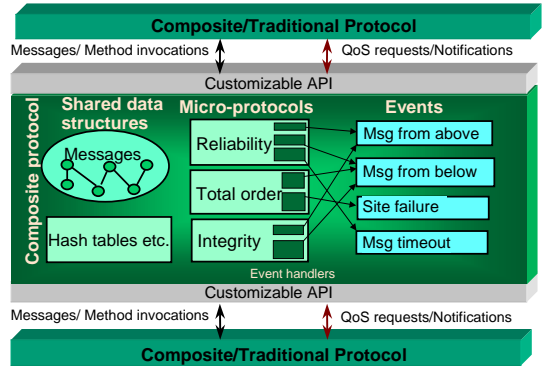
- **Support for configurable solutions**
 - Ability to customize properties to the characteristics of the execution environment and the needs of the application.
- **Support for adaptive behavior**
 - Ability to change execution behavior dynamically to react to changes in the execution environment or the application.

Cactus ⇒ configuration and customization
 Cholla ⇒ adaptation

Cactus: Building Highly Configurable Software

- Both a programming model and an implementation framework for building customized software from collections of software modules.
- Highlights:
 - Fine-grain configuration and customization.
 - Multiple types of attributes and properties, each implemented by a collection of alternative modules.
 - Combination of hierarchical and non-hierarchical composition.
- Focus:
 - Communication-oriented services in networks, i.e., protocol stacks and distributed services (but more general).
 - Highly customizable Quality of Service (QoS) attributes related to fault tolerance, timeliness, security, etc. (but useful for other reasons).
- Addresses challenge of module interaction in highly-configurable software.

Cactus Approach



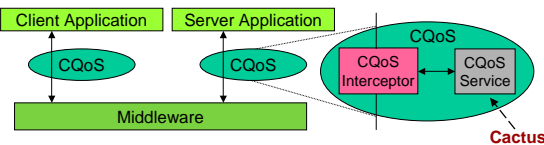
Cactus Model

- Protocol/service = composite protocol.
 - Provides service-specific API.
- Property/QoS attribute = micro-protocol (MP).
 - MPs interact using an events, shared data, and dynamic messages.
 - Mechanisms provide decoupling of MPs ⇒ configurability.
- Service customization = choose appropriate MPs.
- Dynamic adaptation = load/activate/deactivate MPs at runtime.
- Two implementations of Cactus 3.0.
 - C version running on different variants of Unix.
 - Java version.

Example Protocols and Services

- Configurable Transport Protocol (CTP)
 - Ordering, reliability, flow/congestion control, security.
- Secure and Survivable Communication (SecComm)
 - Privacy, authenticity, integrity, replay prevention, combinations.
- Configurable Quality of Service (CQoS)
 - Adding transparent multi-dimensional QoS customization to distributed object systems.
- Distributed System Monitoring Service (CDSMon)
 - Function to be monitored.
- Location-Based Services (LBS)
 - Functionality based on location for mobile services.
- Ad-Hoc Networking (AHN)
 - Dynamic QoS
- AT&T Enterprise Messaging Network (EMN)
 - Per request QoS for mobile service platforms
- Others
 - RTD channels, group RPC, membership, configurable DSM,....

CQoS Architecture (Jun He)



- CQoS consists of two components:
 - Application and platform-specific CQoS interceptor generated from IDL.
 - Generic CQoS service component implements customizable QoS using Cactus.
- Micro-protocols include:
 - Fault tolerance: ActiveRep, PassiveRep, TotalOrder, MajorityVote, Membership, StateRecovery...
 - Security: DESPrivacy, Authentication, AccessControl ...
 - Timeliness: PrioritySched, QueueSched, TimedSched.
- Semantically different combinations of micro-protocols provide semantically different variations of multi-dimensional QoS.

Adaptive Systems

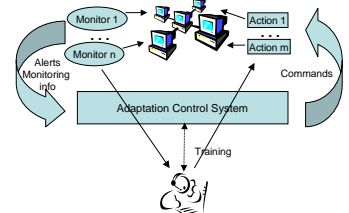
Dynamically changing system behavior.

Motivation:

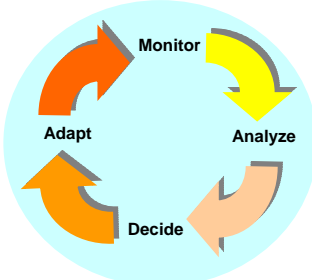
- Short term ⇒ react to changes in the environment: failures, spam/virus/worm attacks, flash crowds, change in wireless connectivity, intrusions
- Long term ⇒ system evolution: updating hardware, software, configuration over time

Adaptive actions:

- Change parameters: router configuration, video frame rate, spam definitions (value adaptations)
- Change software modules: video encoder, caching (algorithmic adaptations)
- Change resource allocation: bandwidth, CPUs (resource adaptations)



Execution Control Feedback Loop



Each phase can be complex in large networked systems:

- Monitoring involves data across multiple hosts and multiple sources.
- Analyzing may involve heuristics or evaluation over time.
- Decision may involve evaluating tradeoffs or distributed algorithms.
- Adaptation may involve distributed coordination across multiple hosts.

All must be done in a running system and an environment that continues to change.

Adaptation mechanisms versus policies:

- Mechanisms provide hooks for monitoring and effecting changes as well as protocols for data collection, analysis, and adaptation coordination.
- Policy encapsulates tradeoff analysis and "business logic".

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Cholla Adaptation Architecture

- Support for value and/or algorithmic adaptations.

Challenges:

- Decoupling control from regular functionality.
- Coordinating adaptations
 - Inter-component coordination on a single host
 - Inter-host coordination for distributed services
- Composition of adaptation policies.
- Developing appropriate adaptation policies.
- Efficient realization of policies.



Solution: Cholla adaptation architecture

- Uses Cactus as underlying platform for implementing adaptive mechanisms and protocols.

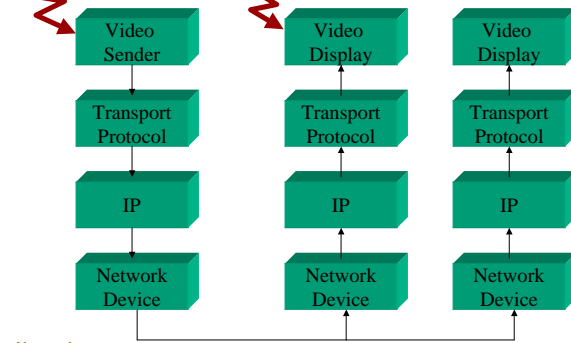
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CPU Availability

Power Availability

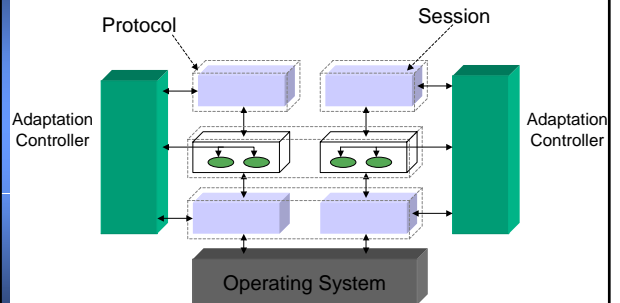


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Software Architecture

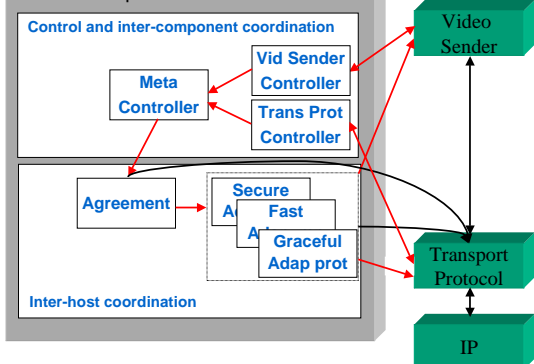


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Adaptation Controller



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Adaptation Controller

- Implements execution feedback control loop:

- Monitors system state and controls adaptation.

Monitoring:

- Input variables from controlled components.
- Input from external monitoring.

Control:

- Generates outputs based on inputs plus adaptation policies.
- Changes execution parameters in controlled components (value adaptations).
- Orchestrates module changeovers (algorithmic adaptations).

Implementations:

- FLAC: Fuzzy logic based adaptation controller. Focuses on value adaptations and inter-component coordination.
- CAC: Cactus based adaptation controller. Focuses on algorithmic adaptations and inter-host coordination.
- Others possible....

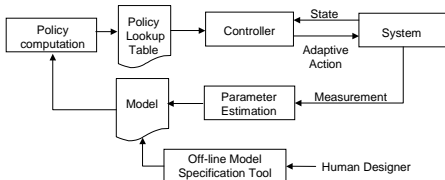
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Policy Generation (Kaustubh Joshi, Bill Sanders)

- Goal: Use stochastic models of system and environment to generate optimal policies for selecting adaptive actions.



- Formulation of the problem as a Markov Decision Process
 - Must deal with state space explosion: state aggregation, model decomposition
- Currently applying to AT&T EMN system.

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Conclusions and Future Work

- Useful system abstractions are the key to building a highly dependable information infrastructure for e-society.
- Our research is addressing issues related to building such abstractions:
 - Cactus: flexible fine grain configuration based on two-level composition model.
 - Cholla: Control and coordinated adaptation.
- Future work
 - Using Cactus and protocols/services built using Cactus.
 - New protocols for cross-host coordination.
 - Policies, policies, policies!

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For More Information

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