Modular Security: Design and Analysis

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Talk for Advancement to Candidacy

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Outline

- Research Context:
  - How to design and analyze security of a software system composed of modules?
- Security
  - Confidentiality, Integrity, Availability
  - Policy, Model, Mechanism
  - Access Control Models
  - Information Flow Models
- Module types and connection mechanisms
- Survey framework
- Surveyed techniques
- Assessments and research issues

Disclaimer

- This is a software talk
  - It views security from the software perspective
- Limited addressing of security
  - Not covered: policy composition, trust management, …
  - Future research probably will address more of them

Research Context

- A system is composed of modules. Modules can be heterogeneous. A system has security property, so does a module.
- Given a set of modules, how can we design a system so it can be secure?
- Given a system of modules, how can we analyze its security?

Security: Basic Properties

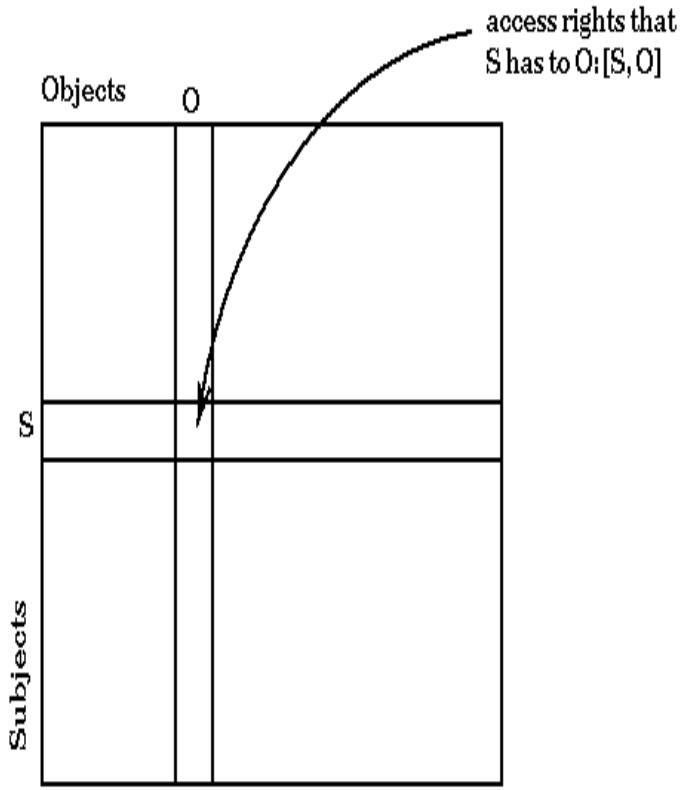
- Confidentiality
  - No improper information disclosure
- Integrity
  - No improper information modification
- Availability
  - No improper denial of service

Security: Policy, Model, and Mechanism

- Policy
  - Goals to be achieved and rules to be enforced
- Model
  - Formal representation of policies
  - Models: access control, information flow, others
- Mechanism
  - Hardware/software used to implement policies
  - Reference Monitor/Trusted Computing Base (TCB) (Anderson, 1972)
  - Tamper-proof, Non-bypassable, Small

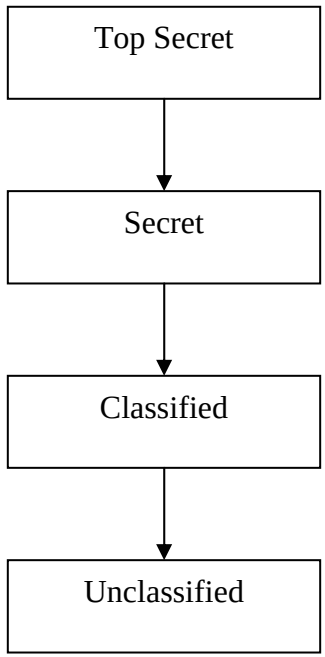
Security: Access Control Discretionary

- Access is based on identify of subject (principal, requestor), object (resource), and right (permission, privilege).
  - Lampson, 1971; Harrison-Ruzzo-Ullman, 1976;
- Access Control Matrix
  - Access Control List
  - Capability



Security: Access Control Mandatory

- Multi Level Security (MLS)
- Confidentiality
  - Bell-LaPadula, 1975
  - No read-up, no write-down
- Integrity
  - Biba, 1977
  - No read-down, no write-up



Security: Access Control Others

- Brewer-Nash, 1989
  - Chinese Wall
  - Dynamic mandatory control; dynamic separation of duty
- Clark-Wilson, 1987
  - Commercial settings
  - Authentication, audit, well-formed transactions, separation of duty
- Role-based Access Control (RBAC)
  - Ferraiolo-Kuhn, 1992; ANSI Standard, 2004
  - Role as an extra-level of indirection
  - Ease of management, roles hierarchy, timing and dynamism

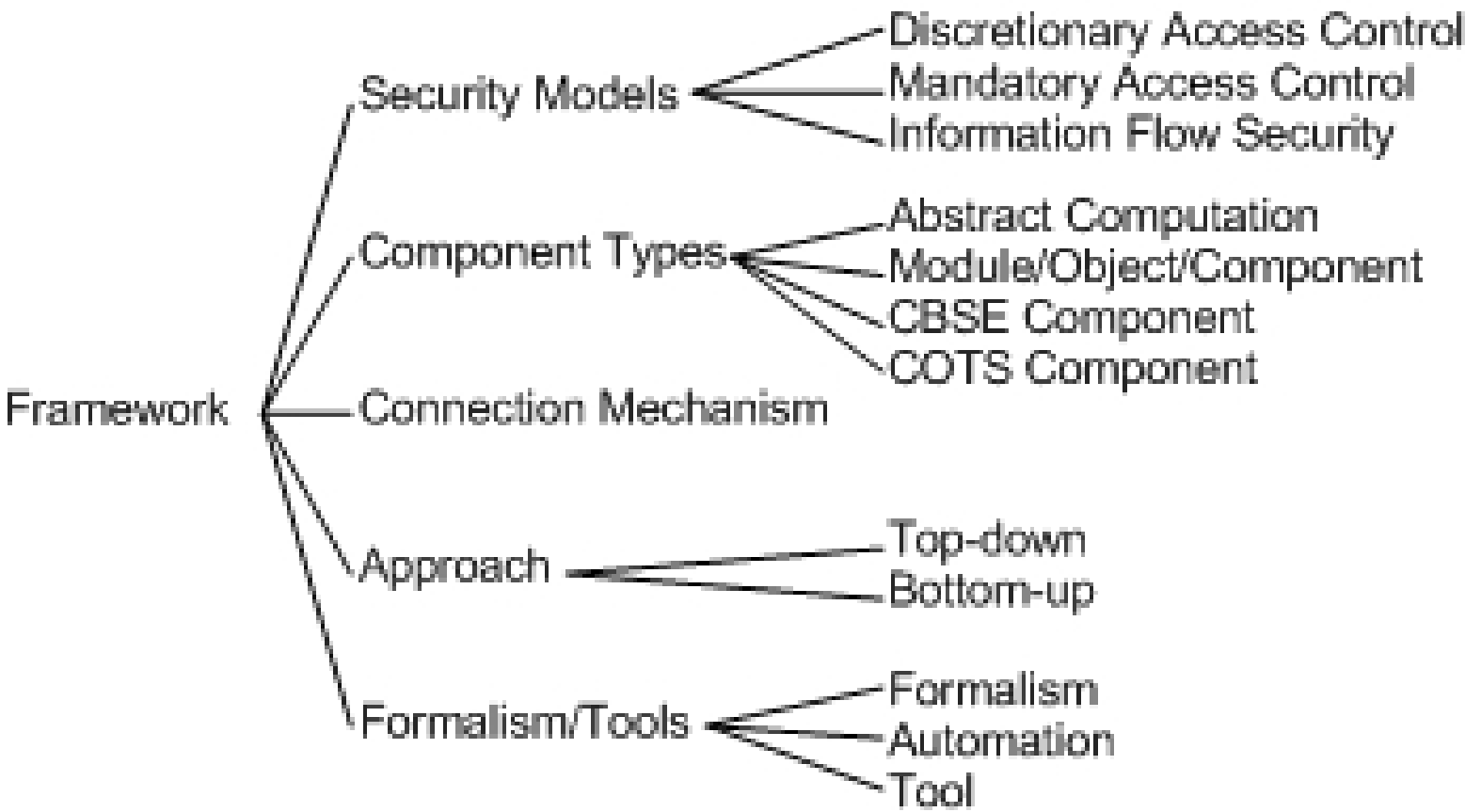
Security: Information Flow Models

- Confidentiality (Secrecy) Model
- Covert Channels: storage and timing
- First: Non-Inteference
  - Goguen-Meseguer, 1982
- Many following definition:
  - Non-deducibility on input (1986), Restrictiveness (1988), Correctability (1988), Non-deducibility on strategy (1990)

Components and Connections (Composition)

- Abstract Computation
  - Logic (conjunction); Trace (input/output); Process Algebra (common event)
- Module/Object/Component
  - Procedure call, event-based; Connector;
- Component-based Software Engineering (CBSE) Component
  - Procedure call; broker; container
- Common-Off-The-Shelf (COTS) Component
  - Custom connection

Framework of Survey



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  - ✓ How to design and analyze security of a software system composed of modules?
- ✓ Security
  - ✓ Confidentiality, Integrity, Availability
  - ✓ Policy, Model, Mechanism
  - ✓ Access Control Models
  - ✓ Information Flow Models
- ✓ Module types and connection mechanisms
- ✓ Survey framework
- ✸ Surveyed techniques
- ✸ Assessments and research issues

Surveyed Techniques

- Formal Techniques
- Wrappers
- Agents
- Meta Object Protocol (MOP)
- Components
- General composition frameworks
- Aspects
- Architectural approaches

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Formal I: Albadi-Lamport / Alpern-Shneider

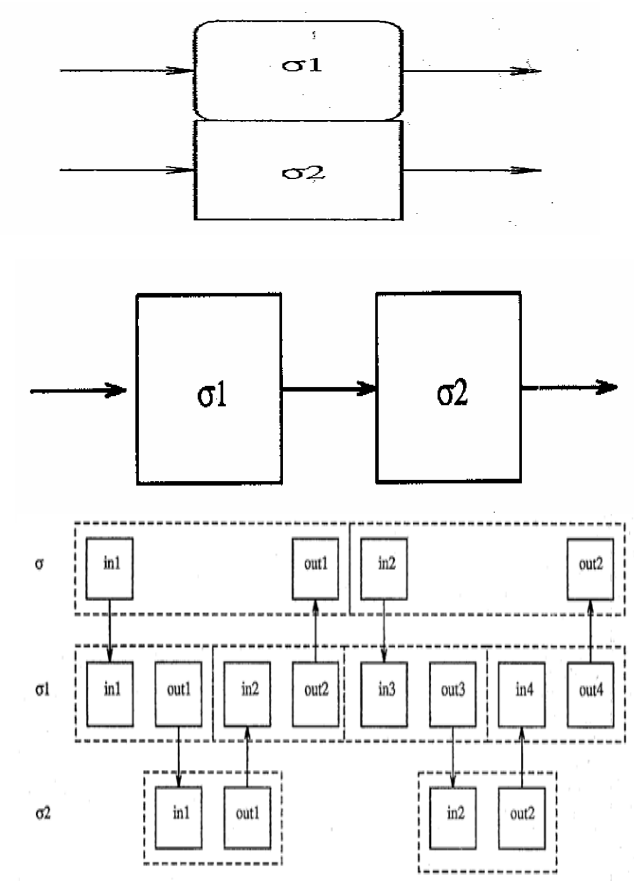
- Composing Specifications, Albadi-Lamport, 1990
- Defining Liveness, Alpern-Shneider, 1985
- Transition, trace, property
  - Systems and properties are sets of traces
  - Safety and liveness property
- Reasoning of composite behavior
  - Composition: what can be composed
  - Refinement: conjunction implies system

Application and Limitation

- Has been used to verify integrity
  - Formal Development Methodology, early 80s
  - Composability for Security Systems, late 90s
- Effective, but labor intensive
  - Theorem prover
- Inapplicable to confidentiality
  - Safety and liveness are sets of traces
  - Confidentiality are power sets of traces
  - Composition opens new chances of interaction and observation for leaking

Formal II: Information Flow Security

- Given a component with one property and a component with potentially different properties, when they are composed using one composition construct, what property will the composite system satisfy?
- Composition Construct: Product, Cascade, Feedback



Theories and Applications

- Many unifying frameworks
  - Trace-based: Selective Interleaving Function, McLean, 1994
    - Take two traces and produce a third one
  - Process Algebra-based: Secure Process Algebra, Focardi, 1998
    - Can processes accept the same events?
  - Logic-based: MAKS, Mantel, 2002
    - Predicates on trace operations
- Few real applications
  - No consensus, remote from real systems, primitive composition, difficult to build

Summary of Formal Techniques

Technology	*Security Model*	*Component Type*	*Connection Mechanism*	*Approach*	*Formalism & Tools*
Integrity Verification, like CSS	Access Control	Logic Formula	Refinement	Top-down	Logic + PVS
Trace-based Information Flow, like SIF	Information Flow Security	Trace	Product, Cascade, Feedback	Bottom-up	Trace
Process Algebra-based Information Flow, like SPA	Information Flow Security	Process	Parallel execution	Bottom-up	Process Algebra + Model Checking

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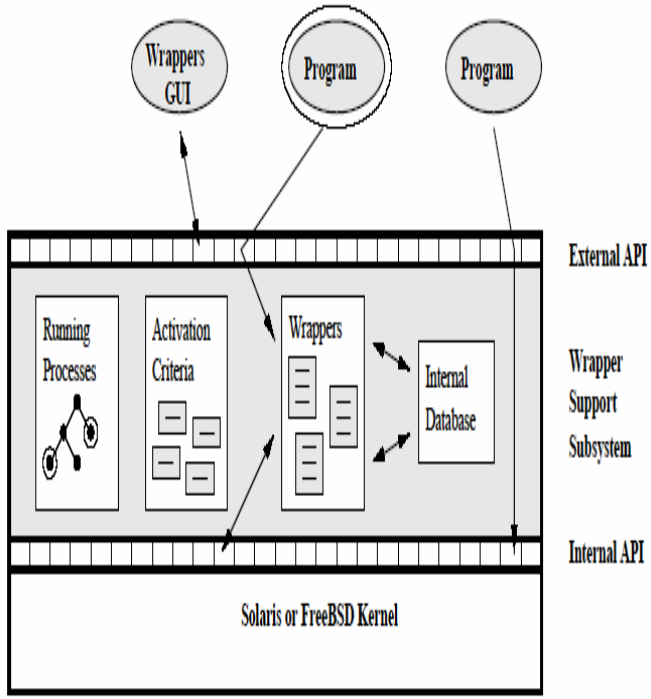
Types of Wrappers

- Wrapper
  - Perform pre and post processing
  - Agents and MOP are more complex wrappers
- Levels of wrappers
  - Application-level wrapper
  - Library function-level wrapper
  - System library-level wrapper
  - System call-level wrapper

Mediator, Hypervisor, and Generic Software Wrapper

- Mediator: Balzer and Goldman, 2000
  - Library function level, Windows
  - Binary patch, write-protection, injection in process creation
- Hypervisor, Mitchem et al., 1997
- Generic Software Wrapper, Fraser et al., 2000
  - State machine, pattern
  - Install, activate
  - Models support



Issues in Using Wrappers

- Level applied
  - applicability
- Information available
  - Context of decision
- Security property
  - Relying, augmenting, or replacing
- Supporting extension mechanism
- Portability
- Performance
  - Trust to reduce overhead

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Agents

- More knowledge, more complex, more cooperation, less regular structure
- Secure Access Wrapper, Dawson et al., 1998
  - Mapping between autonomous MLS
- NRL Workflow/Pump, Kang et al. 1998
  - Constructing MLS workflow from single level workflow using Pump
- JIF/Split, Myers et al. 2002
  - Partition source code for secure execution in distrusting hosts

Safebot

- Filman and Linden, 1996
- Ubiquitous, communicating, dynamically confederating, monitoring and controlling existing applications
- Framework: language, compiler, library
- Not implemented

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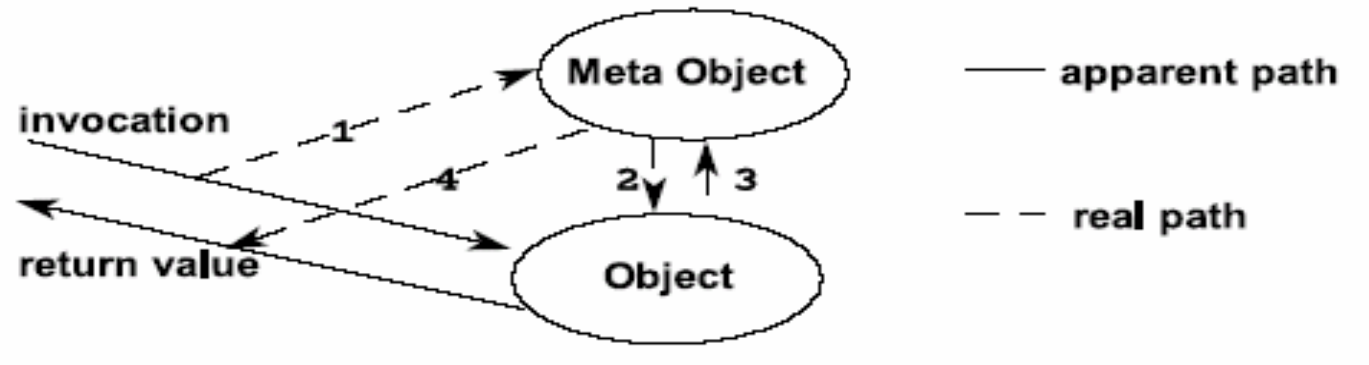
Meta Object Protocol

- Reflection
  - Smith, 1984; Maes, 1987
- Meta Object Protocol
  - Kiczales et al., 1991
- Process

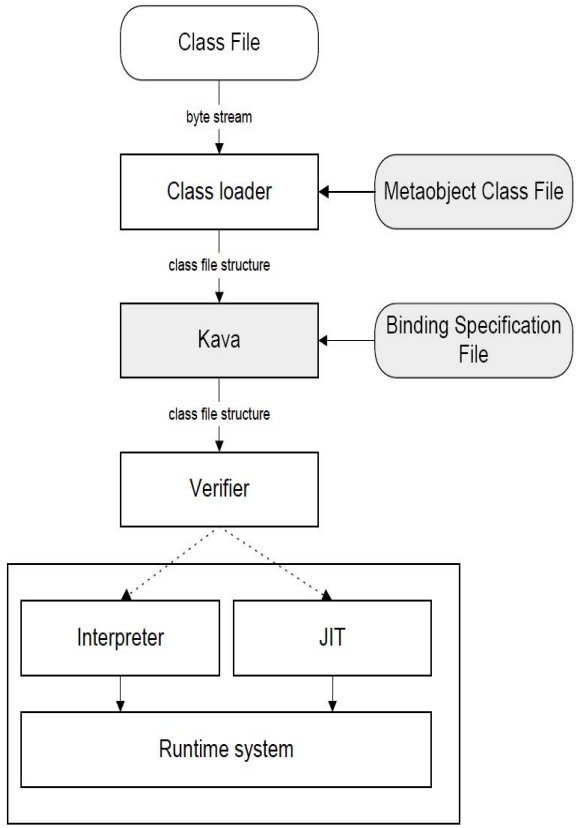


MOP and Security

- The Actor Model
  - Base actor and meta actor
- Security Meta Object
  - Riechmann, 1997
  - Attach meta-objects to possible references
  - Roles of meta references, roles and domains
- Java MOP
  - Compile-time, load-time, proxy-based runtime, and VM-based run time
  - Impact on permission sets

Kava

- Welch and Stroud, 1999
- Bytecode rewriting
  - Load time,
  - Selective,
  - Type-safe
- Capability
  - Method, constructor, field, exception
  - Spec file
  - Non-bypassability
    - User defined class loader
    - System defined class loader
    - Merged base and proxy references
- Security
  - Access Control,
  - Clark-Wilson: field, method, log.



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Components

- Computer Security Contract
  - Khan and Han, 2001
  - Required and ensured
  - Event-based negotiation
  - Active interface with active contracts
- cTLA
  - Hermann, 2003
  - Uses Temporal Logic of Action
  - No dynamic composition yet
- Issues
  - Decidability
  - Trustworthiness of specifications

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Composition Frameworks

Technique	*Component*	*Composition*	*Other feature*
ICARIS 2001	General	Virtual Interface, New Container, Re-Assembly	
CRSS 2000	Low-level services, High-level services	Selection of service providers	Remote provider, Survivability
IDIAN 1999	Intrusion Detection Components	Events exchange, Producer-Consumer negotiation	Formally described negotiation protocol
PSF 2003	View with declarative specification	Dynamic composition	Monitoring for secure session

- Appealing idea
- Drawbacks: Components, connection (dynamic, security), assurance

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Aspects

- From Aspect-Oriented Programming to Aspect-Oriented Software Development
  - Cross-cutting concern,
  - Aspect: advice and pointcuts
- Application to security
  - Aspect-Oriented Security Framework,
    - Shah and Hill, 2003, C programming
  - Feature Selection
    - de Bruin and van Vilet, 2002, requirements

DADO

- Wohlstadter, Jackson, Devanbu, 2003
- Aspect-Oriented Middleware
  - Adaptlet: A pair of a client and a server
  - Extends IDL with advice and request, “that”
  - Implemented as source or binary instrumentation on existing CORBA channel
- Security: injecting security checks
  - Example: contactAuthentic advice, check advice, register request
- Middleware, Client/Server, Static IDL

Component Virtual Machine

- Duclos, Estublier, and Philippe, 2002
- Combines container and AOP
  - Container based approach
    - Target environment, callback, user flexibility
  - AOP limitations
    - Source code, transformation vs. interpretation, compile time
- Utilizes MOP for user flexibility
- Aspect Description Language and Aspect User Language
  - So user can specify how to use aspects
  - Security: check, application, generation
- Callbacks, deployment support, user-defined aspect

Summary of Aspect Techniques

Technology	*Security Model*	*Component Type*	*Connection Mechanism*	*Approach*	*Formalism & Tools*
A-TOS/JAC	Access Control	Base + Aspect	Meta Object, Meta Class	Top-down, Bottom-up	
AOSF		Base + Aspect	Weave	Top-down	Weaver
DADO	Access Control	Adaptlet	Extended CORBA	Top-down Bottom-up	Extended IDL; service and request
CVM	Access Control	Deployable Component	Container-based interception; dynamic composition	Bottom-up	Aspect Description Language and Aspect User Language

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Approaches without connectors

- ASTER
  - Bidan and Issamy, 1997
  - Among the first for specifying security requirements for components and form composition based on those requirements
  - Uses a module interconnection language
  - Specification for encryption and authentication choices
  - Access control policies: combine subjects and rules
  - Limitations: security primitives, spec match, lack of connector, compositions of compositions

Approaches without connectors, cont.

- System Architecture Model
  - Deng et al., 2003
  - Combines Petri nets and Temporal Logic
  - Top-down approach for verifying constraints on components
  - Essentially verification of safety
- Object-Oriented Labeling
  - Peter Herrmann, 2001
  - Extend standard object-orientation notations, adopt Common Criteria
  - Uses Myers's labeling model

Approaches with connectors

- Connector Transformation
  - Spitznagel and Garlan, 2001
  - Problem: add Kerberos to RMI
  - Alternatives: modify application, modify generator
  - Solution: transformations on connectors
    - Transforming data, combining connectors, adding a role, adding/removing states, imposing a connector
  - Limitation: connector-specific transformations

Approaches with connectors, cont.

- SADL
  - Riemenschneider et al., since 1997
  - Continuous refinement proof
    - Security-preserving proof, checkable proof
  - Security: Distributed Transaction Processing with MLS security
    - Application, resource manager, transaction manager
    - Theory interpretation and faithful interpretation between levels: exact mapping
    - Manual proof
    - Lower-level proofs can reuse mapping and higher-level proofs
  - Design a lot, specify some, prove a little

Summary of Architectural Approaches

Technology	*Security Model*	*Component Type*	*Connection Mechanism*	*Approach*	*Formalism & Tools*
Object-Oriented Labeling	Information Flow Security	Object		Top-down	Decentralized Labeling; Graph Rewrite
ASTER	Access Control	Component	Component selection	Bottom-up	Logic
SAM	Access Control	Petri net	Petri-net composition	Top-down	Petri net and Temporal Logic
Connector Transformation	Secure Communication	Regular component	Transformed secure connector	Top-down	Transformations
SADL	Mandatory Access Control	Component	Security-preserving Transformation	Top-down	Logic, PVS

Assessments of Surveyed Techniques

- Formal techniques
  - Scalability and usability
- Wrappers
  - Mature; can be challenging in implementation
- Agents
  - Flexibility vs. applicability
- Meta Object Protocol (MOP)
  - Low-level implementations for flexibility
- Components
  - Need further investigation on security specifications
- General composition frameworks
  - Not well defined, overly ambitious
- Aspects
  - Abstraction, use of MOP and Components, description and enactment
- Architectural approaches
  - Software architecture needs support for security

Research Issues

- Foundations: why is it hard?
  - What kind of security cannot be easily modeled like functionality?
  - How can we bridge the gap between theory and practice?
- Security properties
  - Integrity, confidentiality, availability
  - How to describe the requirements of these properties for components and systems?
- Secure software architecture
  - Will an architectural approach succeed in providing security?
  - How can we make a software architecture secure?
  - Will a connector be a right place to enforce security?
- Description and enactment
  - What are the right mechanisms for description and enactment?
  - Security/Assurance vs. Flexibility/Generality

Research Plan

- Architecture-centered and connector-oriented
- Lightweight formal methods: logic
- Practical security models: advanced access control, trust
- Component specifications on security
- Compositions handled by connectors
- Implementation aids: wrappers, meta-object protocol, and aspects.
- Automatic tools: design, generation, analysis, visualization
- Validation: build and analyze real systems