

Security

An Advanced Introduction

Gernot Heiser

COMP9242 2005/S2 Week 4

WHAT IS SECURITY?

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 - ... if it is behind a firewall?

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- Depends? On what?

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- Perfect security is generally unachievable
 - need to be aware of *threads*
 - need to understand what *risks* can be tolerated

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 - trustworthiness of data: data correctness
 - trustworthiness of origin of data: authentication
- Availability: prevent denial of service
 - ensuring data is usable when needed

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- An *attack* is an attempt by the *attacker* to violate security
 - generally implies exploiting a weakness
- A *threat* is a potential for an attack

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- A *threat* is a potential for an attack
- There is never a shortage of attackers, hence in practical terms
 - threat \Rightarrow attack
 - weakness \Rightarrow violation

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- false denial of receiving
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- temporarily inhibiting service
- attack on availability

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- permanently inhibiting service
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- Partitions system state into allowed and disallowed
- Ideally mathematical model
- In reality natural-language description
 - ★ often imprecise, ambiguous, inconsistent, unenforceable
 - ★ Example: transactions over \$10k require manager approval
 - but transferring \$10k into own account is no violation

SECURITY MECHANISMS

- Used to enforce security policy
 - computer access control (login authentication)
 - OS file access control system
 - controls implemented in tools
- Example:
 - Policy: only accountant can access finance system
 - Mechanism: on un-networked computer in locked room with only one key
- A secure system provides mechanisms that ensure
 - prevention
 - detection
 - recovery

of violations

ASSUMPTIONS

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 - eg lock is secure, key holders are trustworthy
- Invalid assumptions *void* security!
- Problem: assumptions are often implicit and poorly understood
- Security assumptions must be
 - clearly identified
 - evaluated for validity

TRUST

- Systems always have *trusted entities*
 - hardware, operating system, sysadmin...
- Totality of trusted entities is the *trusted computing base* (TCB)
- Assumed to be *trustworthy*!

TRUSTED COMPUTING BASE

The totality of protection mechanisms within a computer system — including hardware, firmware and software — the combination of which is responsible for enforcing a security policy.

A TCB consists of one or more components that together enforce a unified security policy over a product or system.

The ability of the TCB to correctly enforce a security policy depends solely on the mechanisms within the TCB and on the correct input by system administrative personnel or parameters related to the security policy. [Gol99]

POTENTIALLY INVALID ASSUMPTIONS

- The security policy is unambiguous and consistent
- The mechanisms used to implement the policy are correctly designed
- The union of mechanisms implements the policy completely
- The mechanisms are correctly implemented
- The mechanisms are correctly installed and administered

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- Assurance does not *guarantee* correctness/security!

ASSURANCE: ESTABLISHED APPROACHES

US DoD ORANGE BOOK [DoD86]

- Defines security classes
 - D: minimal protection
 - C1-2: discretionary access control
 - B1-3: mandatory access control
 - A1: verified design
- Systems can be certified to a certain class
 - very costly, hence only practicable for big companies
 - most systems only certified C2 (not more than Unix-style security)

ASSURANCE: ESTABLISHED APPROACHES

COMMON CRITERIA [NIS99]

- ISO standard, developed out of Orange Book
- Seven evaluation assurance levels (EALs)
 - EAL1: functionally tested
 - EAL2: structurally tested
 - EAL3: methodically tested and checked
 - EAL4: methodically designed, tested and reviewed
 - EAL5: semiformally designed and tested
 - EAL6: semiformally verified design and tested
 - EAL7: formally verified design and tested

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 - EAL7: formally verified design and tested
- Higher levels imply more thorough evaluation
 - not necessarily better security
 - implementation not verified

SUMMARY

- Computer security is complex
 - depends on many aspects of computer system
- Policy defines security, mechanisms enforce security
- Important to consider:
 - what are the assumptions about threats and trustworthiness
 - incorrect assumptions \Rightarrow no security!
- Security is never absolute
 - given enough resources, mechanisms can be defeated
 - important to understand limitations
 - inherent tradeoff between security and usability
- Human factors are important
 - people make mistakes
 - people may not understand security impact of actions
 - people may be less trustworthy than thought

SECURITY POLICIES: 2 CATEGORIES

- Discretionary (user-controlled) policies
 - e.g. a_1 can read a_2 's object only with a_2 's permission
 - user decides about access
- Mandatory (system-controlled) policies
 - e.g. certain users cannot ever access certain objects
 - no user can change this

SECURITY POLICY MODELS

- Represent a whole class of security policies
- Most system-wide policies focus on confidentiality
 - e.g. military-style multi-level security models
 - classical example is Bell-LaPadula model [BL76]
 - most other based on this
- Other cases:
 - ★ Chinese-wall policy focuses on conflict of interest
 - ★ Clark-Wilson model focuses on separation of duty

BELL-LAPADULA MODEL

- Each object has a *security classification* $L(a)$
- Each agent has a *security clearance* $L(o)$
- Classifications and clearances from hierarchical *security levels*
 - top secret > secret > confidential > unclassified

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- Rule 2 (“* Property”):
 - a can write o only if $L(a) \leq L(o)$
 - prevents *leakage* (accidental or by conspiracy)

BELL-LAPADULA MODEL EXTENSIONS

- Can combine with discretionary access rights (read/write permissions on specific objects)
- Can add orthogonal *security categories* indicating types of data
 - restrict access to relevant categories
 - Denning's lattice model [Den76]

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- Based on *access control*
 - ★ discretionary access control (DAC)
 - users can change access to objects
 - ★ mandatory access control (MAC)
 - access rights centrally controlled

ACCESS RIGHTS

- Simple rights

- ★ read, write, execute/invoke, send, receive...

- Meta rights

- copy (propagate a right to another agent)

- own (change rights of an object or agent)

ACCESS CONTROL MATRIX

Agents	Objects			
	S_1	S_2	O_3	O_4
S_1	terminate	wait, signal, send	read	
S_2	wait, signal, terminate			read, execute write
S_3		wait, signal, receive		
S_4	control		execute	write

Note: Agents are objects too!

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- Columns define objects' *accessibility*
- Dynamic data structure: frequent
 - permanent changes (e.g. chmod)
 - temporary changes (e.g. setuid)
- Very *sparse* with many repeated entries
- Usually not stored explicitly.

ISSUES FOR PROTECTION SYSTEM DESIGN

- Propagation of rights:
 - Can agent grant access to another?
- Restriction of rights:
 - Can agent propagate restricted rights?
- Revocation of rights:
 - Can access, once granted, be revoked?
- Amplification of rights:
 - Can unprivileged agent perform restricted operations?
- Determination of object accessibility:
 - Which agents have access?
 - Is object accessible at all (garbage collection)?
- Determination of agent's protection domain:
 - Which objects are accessible?

ACCESS MATRIX IMPLEMENTATION: ACLs

Represent column-wise: *access control list* (ACL):

- ACL associated with object.
 - Propagation: meta-right (e.g., *owner* can `chmod`)
 - Restriction: meta-right
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- Sometimes implicit (process hierarchy).

ACCESS MATRIX IMPLEMENTATION: CAPABILITIES

Represent row-wise: *capabilities*

- *Capability list* associated with agent.
- Each capability confers a certain right to its holder.
 - Propagation: copy capabilities between agents (how?)
 - Restriction: lesser rights require new (“derived”) capabilities
 - Revocation: requires invalidation of capabilities from *all agents*
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- Can have *negative rights*, to:
 - reduce “window of vulnerability”,
 - simplify management of groups of capabilities.
- Successful commercial system: IBM System/38 *et fils*

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- How implemented and protected?
 - **tagged** (protected by hardware),
 - **partitioned** (protected by software),
 - **sparse** (protected by obscurity).

TAGGED CAPABILITIES

- *Tag bit(s)* with every (group of) memory word(s):
 - ★ Tags identify capabilities
 - ★ Capabilities are used and copied like “normal” pointers
 - ★ Hardware checks permissions on dereferencing capability
 - ★ Modifications turn tags off
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 - Restriction requires kernel to make new capability.
 - Revocation virtually impossible (memory scan!)
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- **IBM System/38, AS/400, i-series; many historical systems.**

PROTECTED PROCEDURE CALL (AS/400)

- AS/400 has a segmented memory architecture.
- Capabilities confer rights over segments.
- Capabilities can confer invocation rights.
- Each user has a *profile*, which is essentially a capability list.
- Capabilities can be of *profile adoption* type:
 - On invocation, segment owner's *profile* is added to caller's protection domain.
 - Normal pointers can be dereferenced if the profile contains appropriate capabilities.
 - On return, profile adoption is cancelled.
 - User can denote subset of their profile to be used in adoption (*profile propagation*).

TAGGED CAPABILITIES OUTSIDE RAM

- Disk has no tags.
- AS/400 page size is 4kB.
- Physical disk blocks are 520B, logical blocks 512B.
- Extra 64B per page store tag bits (among others).
 - On page-out page must be scanned and all tags collected.
 - On page-in all tags must be reconstituted.
 - Significant processing overhead with all I/O.

TAGGED CAPABILITIES SUMMARY

- Secure through hardware protection.
- Convenient for applications (appear as “normal” pointers).
- Checked by hardware \Rightarrow fast validation.
- Hardware solution is not for everyone.
- Capability hardware is complex (and slow?)
- Separate mechanisms required for I/O and distribution.

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- Hydra [CJ75], Mach [RTY⁺88], KeyKOS [BFF⁺92], Grasshopper [DdBF⁺94], EROS [SSF99] and many others.

PROPAGATING PARTITIONED CAPABILITIES (MACH):

- Capabilities can be propagated via IPC.
 - ① User must insert capabilities (clist indices) into special field in message.
 - ② Kernel looks up clists and inserts representation of “real” capability (*marshaling*).
 - ③ Receiver’s kernel inserts capabilities into receiver’s clist.
 - ④ Kernel replaces capability in message by clist index.

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 - ③ Receiver’s kernel inserts capabilities into receiver’s clist.
 - ④ Kernel replaces capability in message by clist index.
- Can be simplified if IPC is local.
- Amplification can be performed by schemes similar to AS/400.

PARTITIONED CAPABILITIES SUMMARY

- Secure through kernel protection.
- Validation at mapping time \Rightarrow apps use “normal” pointers.
- Fast validation (clist check is simple, validation cached by MMU).
- Propagation requires marshaling and kernel intervention.
- Reference counting possible to detect unaccessible objects.

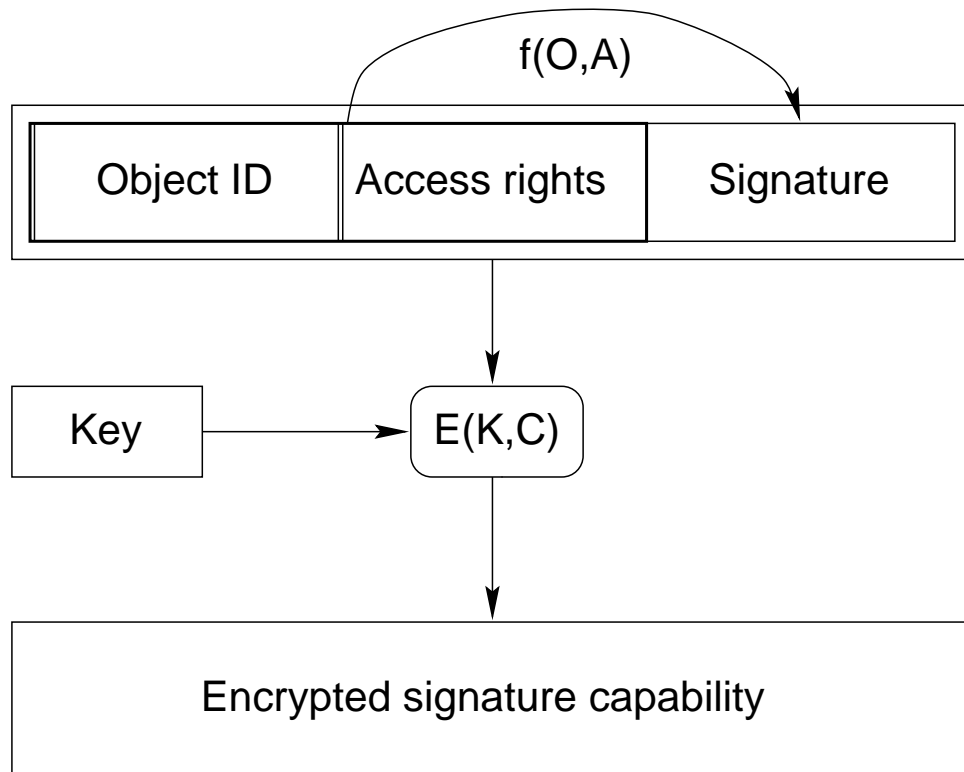
SPARSE CAPABILITIES

Basic idea similar to encryption:

- Add bit-string to make valid capabilities a very small subset of the capability space.
- Can be encrypted object info or something like a password.
- Capabilities are pure user-level objects, which can be passed around like other data.
- Appropriate for user-level servers.

EXAMPLE: SIGNATURE CAPABILITIES

“**First Migration Scheme**” [GL79], designed to allow migration of tagged capabilities in distributed systems.

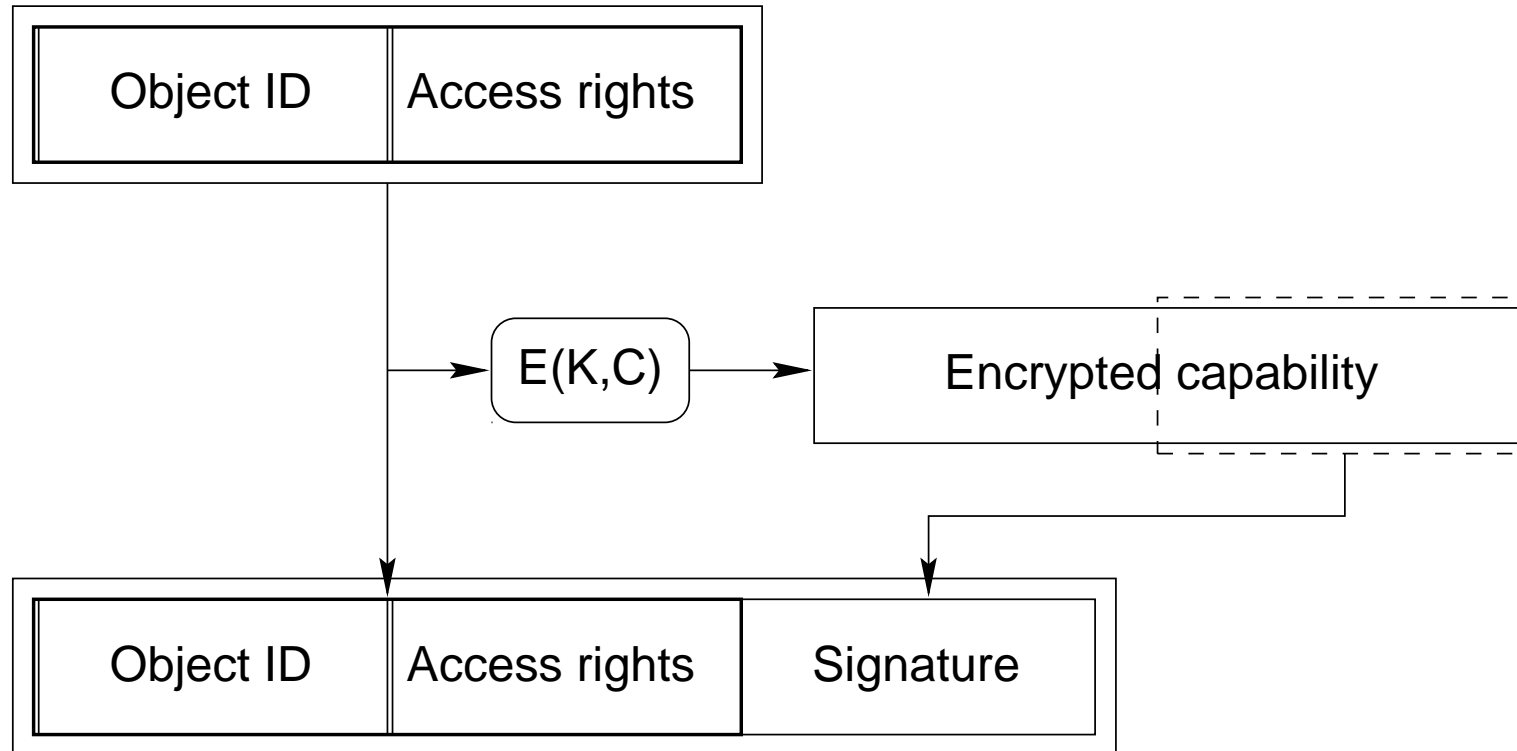


- + tamper proof via encryption with secret kernel key
- + can freely be passed around
- need to decrypt on each validation
- users do not know which object capability refers to

● f : one-way function (secure hash), E : encryption function

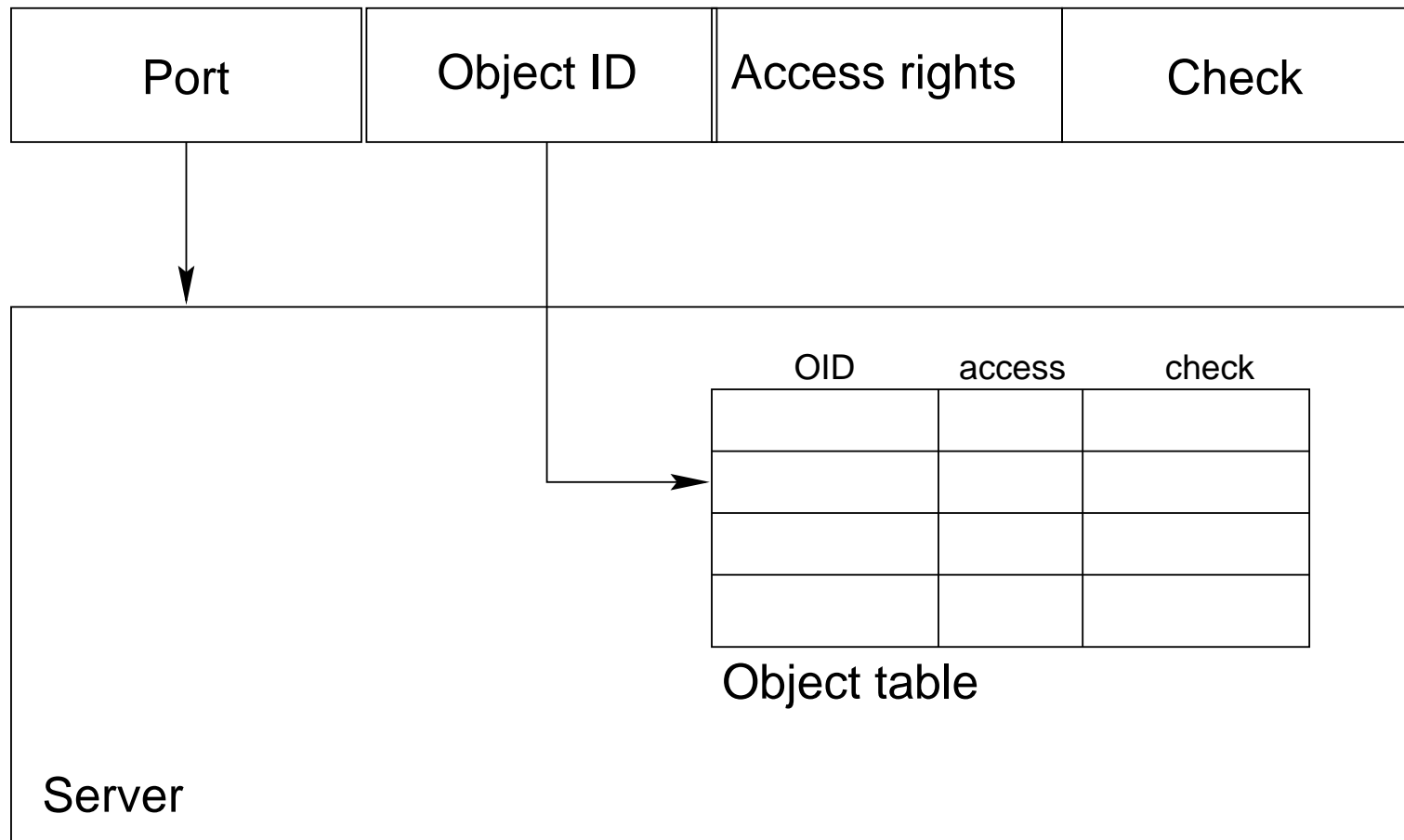
EXAMPLE: SIGNATURE CAPABILITIES

“Second Migration Scheme” [GL79]



Object ID visible, yet still tamper proof.

EXAMPLE: AMOEBA'S CAPABILITIES



Appropriate for user-level servers [MT86].

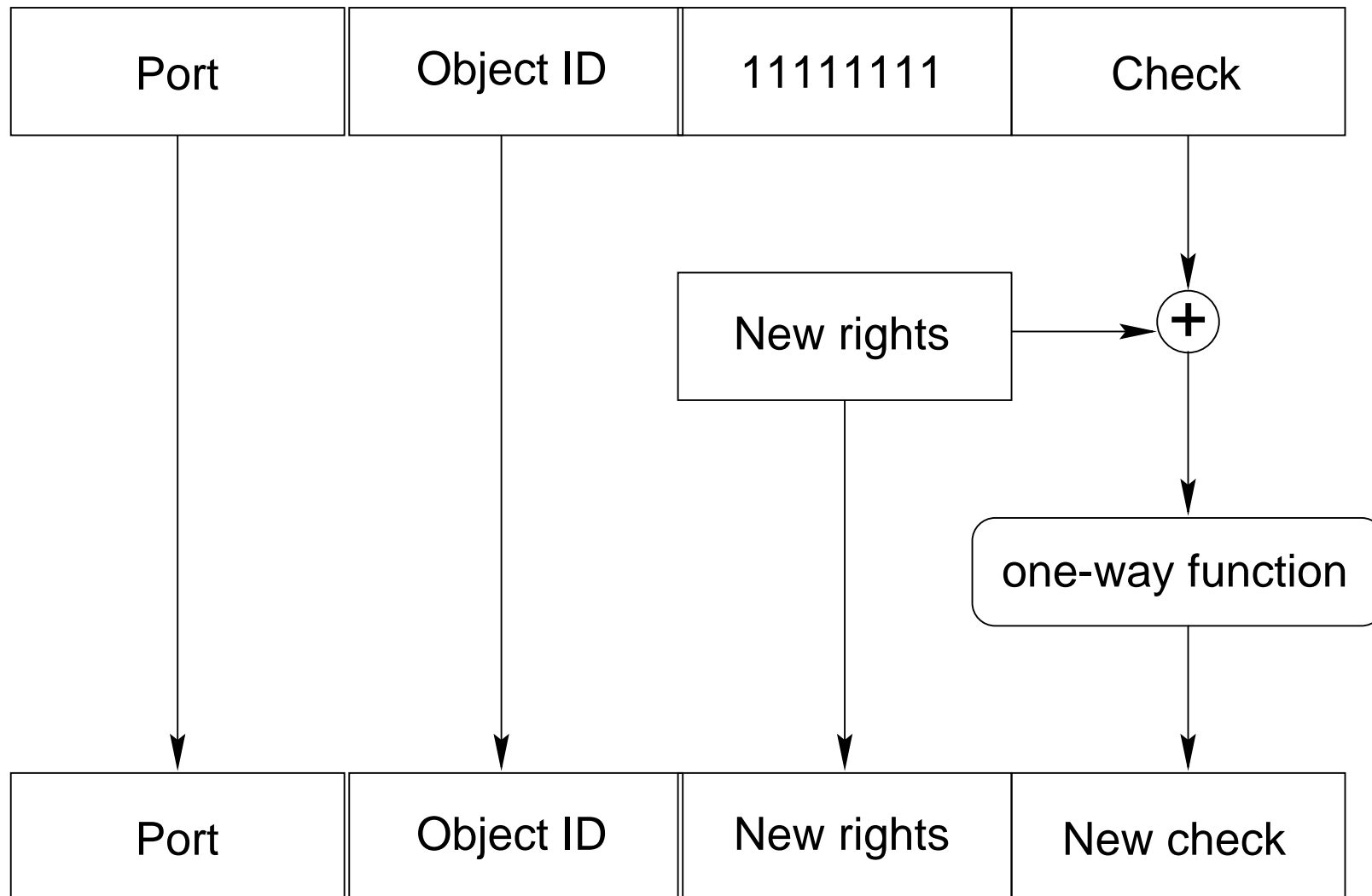
PROPERTIES OF AMOEBA CAPABILITIES

- Port identifies server.
 - Kernel resolves server and caches server location.
- Port IDs are large (48-bit) sparse numbers.
 - Knowledge implies send rights.
- Creator (“owner”) has all rights.
- Server uses OID to look up rights, checks fields to validate.

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 - Knowledge implies send rights.
- Creator (“owner”) has all rights.
- Server uses OID to look up rights, checks fields to validate.
 - Validation done by user-level server when invoked.
 - Propagation easy, as capabilities are “normal” data.
 - Restriction requires server to make new capability.
 - Revocation done by server removing entry from object table.
 - But** not very helpful if only one capability per access mode.
 - Amplification possible according to server policies.
 - Accessibility is impossible to determine.
 - Protection domain is impossible to determine.

AMOEBEA RIGHTS RESTRICTION



- Used by server to derive lesser capabilities on request.
- No need to store derived capability in object table.

IMPROVED VERSION (NOT IMPLEMENTED)

- Set of *commuting* one-way functions f_i , one for each access mode bit:

$$f_i(f_j(x)) = f_j(f_i(x)).$$

- To remove access mode i , obtain new check field as:

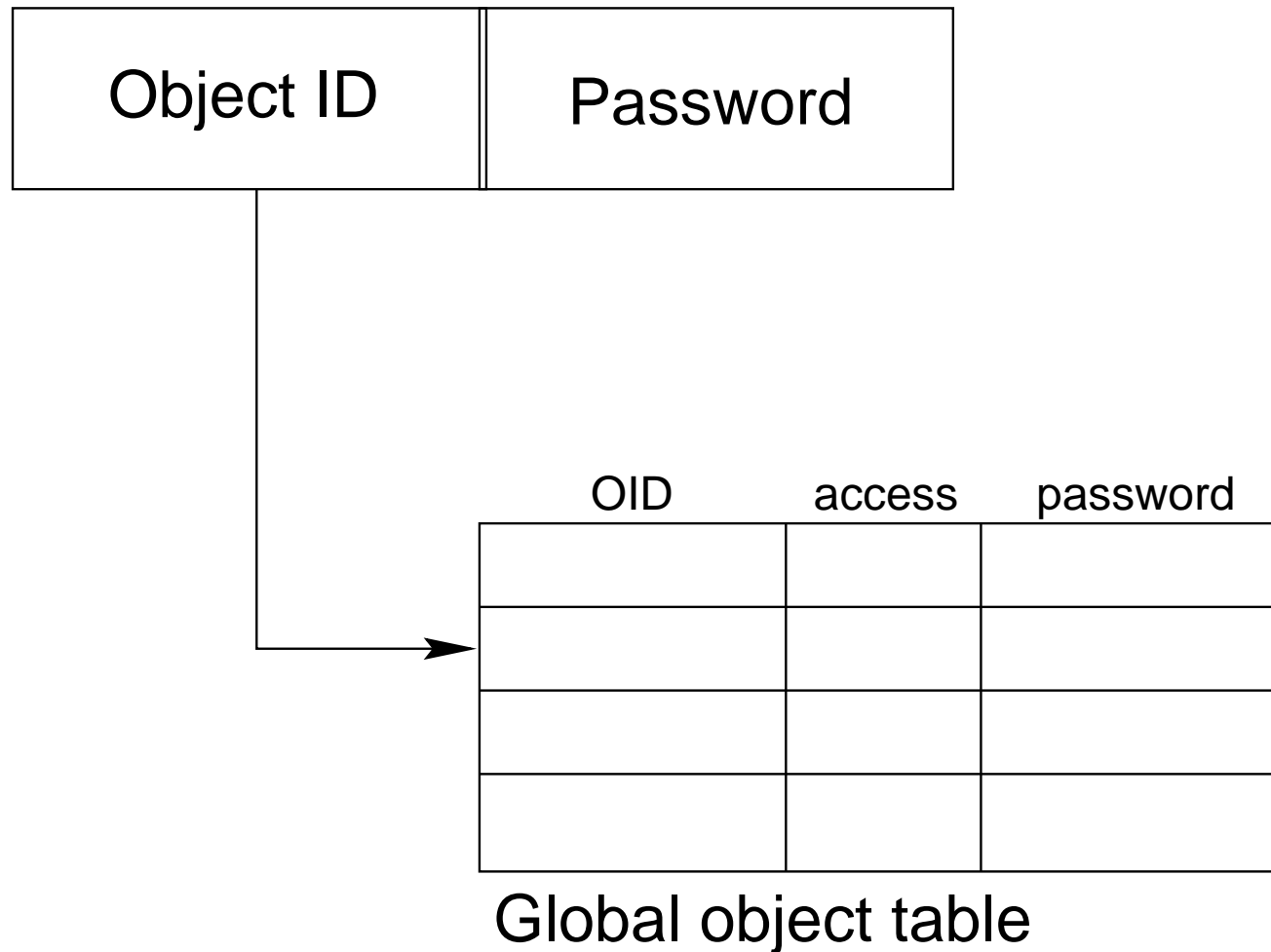
$$C' = f_i(C).$$

- Can be done by user without server intervention.

SERVER AUTHENTICATION: F-BOXES

- Hardware device “F-box” at each network connection
 - When requesting messages for port G , F-box will only accept messages destined for port $P = f(G)$, where f is a one-way function
 - Server publishes P as port ID
 - Intruder who does not know G cannot access messages
- Scheme depends on physical security of F-boxes (or their implementation in the OS).
- Never been implemented (to my knowledge).

PASSWORD CAPABILITIES



- Used in the Monash Password Capability System [APW86], Opal [CLFL94], Mungi [HEV⁺98].

PROPERTIES OF PASSWORD CAPABILITIES

- Passwords must be protected (eavesdropping, Trojan horses).
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- Passwords must be protected (eavesdropping, Trojan horses).
- Separate passwords for different rights (good idea to package rights with caps).
- No encryption \Rightarrow easy to validate.
 - Validation done by kernel on access or presentation and cached by MMU.
 - Propagation easy, as capabilities are “normal” data.
 - Restriction requires kernel to make new capability.
 - Revocation done by kernel removing entry from object table.
 - Amplification possible similar to AS/400.
 - Accessibility is impossible to determine.
 - Protection domain is known to kernel.

SPARSE CAPABILITIES SUMMARY

- Statistically secure (like encryption).
- Validation at mapping time \Rightarrow applications can use “normal” pointers.
- Validation may be slow, but kernel and MMU can cache.
- No kernel intervention required on most operations.
- Reference counting impossible to detect unaccessible objects.

CONFINEMENT

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 - how can you be sure the clients don't make unauthorised copies?
- Need to *confine* program (game, viewer) so it cannot leak data
- Cannot be done with most protection systems!
 - not with UNIX or most other ACL-based systems
 - not with most tagged or sparse capability systems
 - multi-level security has some inherent confinement but wouldn't help for DRM

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- Some protection models can confine in principle
 - e.g. segregated caps system requires all caps to be presented explicitly
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 - EROS has a formal proof of its confinement properties [SW00]
- In practice difficult to achieve confinement due to *covert channels*

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 - a sound access-control system should be *free* of covert channels
 - ★ Covert timing channel uses a temporal ordering relationship among accesses to a shared resource
 - outside access control system
 - difficult to reason about
 - difficult to prevent

COVERT TIMING CHANNELS

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- Require access to a time source
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 - anything else that allows unrelated processes to synchronise
- Critical issue is bandwidth
 - ★ in practice the damage is limited if the bandwidth is low
 - e.g. DRM doesn't care about low-bandwidth channels
 - ★ beware of amplification (e.g. leaking a password capability)!

DESIGN PRINCIPLES FOR SECURE SYSTEMS

- Least privilege
- Fail-safe defaults
- Economy of mechanism
- Complete mediation
- Open design
- Separation of Privilege
- Least common mechanisms
- Psychological acceptability

LEAST PRIVILEGE

- Agent should only be given the minimal rights needed for task
 - ★ minimal protection domain (PD)
 - ★ PD determined by *function*, not *identity*
 - Unix `root` is bad
 - *role-based access control* (RBAC) tries to address this
 - ★ rights added as needed, removed when no longer needed

FAIL-SAFE DEFAULTS

- Default action is no access
 - ★ if action fails, system remains secure
 - ★ if security administrator forgets to add rule, system remains secure
 - ★ “better safe than sorry”

ECONOMY OF MECHANISM

- KISS principle of engineering
- Less code/features/stuff \Rightarrow less to get wrong!
 - ★ makes it easier to fix if something does go wrong
 - ★ complexity is the natural enemy of security
- Also applies to interfaces, interactions, protocols...
- Minimal trusted computing base!

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 - issue for tagged or sparse capability systems
- In practice, this is in conflict with performance
 - ★ caching of buffers, file descriptors etc
 - ★ unacceptable performance in distributed systems
- Should at least limit window of opportunity
 - e.g. guarantee caches to be flushed after some fixed period

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OPEN DESIGN

- Security must *not* depend on secrecy of design or implementation
 - ★ the TCB must be open to scrutiny
 - ★ *security by obscurity* is poor security
 - e.g. the US government's Clipper initiative ('92)
- note that this does not rule out passwords or secret keys
 - ★ but the way they are created/used requires careful *cryptoanalysis*

SEPARATION OF PRIVILEGE

- Require combination of conditions to grant privilege
 - e.g. user is in group `wheel` *and* knows the root password
 - closely related to least privilege

LEAST COMMON MECHANISMS

- Avoid sharing mechanisms
 - ★ shared mechanism \Rightarrow shared channel
 - ★ potential covert channel
- Inherent conflict with other design imperatives
 - ★ simplicity \Rightarrow shared mechanisms

PSYCHOLOGICAL ACCEPTABILITY

- Security mechanisms should not add to difficulty of use
 - ★ hide complexity introduced by security mechanisms
 - ★ ensure ease of installation, configuration, use
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- Security mechanisms should not add to difficulty of use
 - ★ hide complexity introduced by security mechanisms
 - ★ ensure ease of installation, configuration, use
 - ★ systems are used by *humans*
- Inherently problematic
 - ★ security inherently inhibits ease of use
 - ★ idea is to minimise impact
- Security-usability tradeoff is to a degree unavoidable

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