● **Access control principles**
  – access control matrices
  – access control lists
  – capability tickets

● **Types of access control**
  – discretionary access control
  – mandatory access control
  – role-based access control
  – attribute-based access control
Access Control Basics

• What is access control?
  – prevention of an unauthorized use of a resource or use in an unauthorized manner

• In some sense, all of security is concerned with access control

• We look at a more specific notion of access control model

• An access control model specifies who is allowed to access what resource and what type of access is permitted
  – it may also specify when access is permitted

• What makes it hard?
  – interaction between different types of access
• In a broader context, access control is related to the following concepts
  – authentication, identity and credential management
    • creation, maintenance, and verification of user or entity identity and/or credentials
  – authorization and information flow
    • granting rights or privileges based on established trust assumptions and imposing controls on information flow
  – audit and integrity protection
    • system monitoring to ensure proper use of resources and compliance with policies
    • detection of breaches in security and taking corresponding actions and/or making recommendations
• **Reference monitor** mediates access to resources
  
  – **complete mediation** means controlling all accesses to resources
• **Least privilege**
  - each entity is granted the minimum privileges necessary to perform its work
  - limits the damage caused by error or intentional unintended behavior

• **Separation of duty**
  - practice of dividing privileges associated with one task among several individuals
  - limits the damage a single individual can do
  - example:
Access Control Model Basics

- There is a set of resources or objects, $O$, to be protected
  - directories, files, devices, peripherals, even facilities

- There is a set of subjects, $S$, that may obtain access to the resources
  - each subject can have a number of attributes (name, role, groups)
  - each subject is normally accountable for its actions

- Access right or privilege describes the type of access
  - read, write, execute, delete, search

- Access control requirements form rules
  - subject $s$ has read access to object $o$
• The rules can be represented as an access control matrix

• Example

<table>
<thead>
<tr>
<th></th>
<th>Internal</th>
<th>Local</th>
<th>Long distance</th>
<th>International</th>
</tr>
</thead>
<tbody>
<tr>
<td>Public</td>
<td>CRT</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Students</td>
<td>CRT</td>
<td>CRT</td>
<td>R</td>
<td>R</td>
</tr>
<tr>
<td>Staff</td>
<td>CRT</td>
<td>CRT</td>
<td>CRT</td>
<td>R</td>
</tr>
<tr>
<td>Administration</td>
<td>CRT</td>
<td>CRT</td>
<td>CRT</td>
<td>CRT</td>
</tr>
</tbody>
</table>

C = call, R = receive, T = transfer

• Often access control matrices are sparse and can instead be represented as access control lists (ACLs)
• In **ACLs** each object has a list of subjects authorized to access it and their types of access
  – for each object, a column of the access control matrix is stored

• **Example** of ACLs for previous system

  Internal:  Public/CRT, Students/CRT, Staff/CRT, Administration/CRT

  Local:  Students/CRT, Staff/CRT, Administration/CRT

  Long distance:  Students/R, Staff/CRT, Administration/CRT

  International:  Students/R, Staff/R, Administration/CRT

• Do Unix permission bits constitute ACLs?
• With ACLs, it is hard to determine what privileges a subject has

• We can gather information about subject privileges in so-called capability lists
  – for each subject, store a row of the access control matrix

• Example

Public: **Internal/CRT**

Students: **Internal/CRT, Local/CRT, Long dist/R, International/R**

Staff: **Internal/CRT, Local/CRT, Long dist/CRT, International/R**

Administration: **Internal/CRT, Local/CRT, Long dist/CRT, Intl/CRT**

• Each user has a number of capability tickets and might be allowed to loan or give them to others
To address drawbacks of all previous representations, we can have a table with \((s, o, a)\) triples

- is not sparse like access control matrices
- sort by objects to obtain ACLs
- sort by subjects to obtain capability lists

<table>
<thead>
<tr>
<th>Subject</th>
<th>Access</th>
<th>Object</th>
</tr>
</thead>
<tbody>
<tr>
<td>Public</td>
<td>C</td>
<td>Internal</td>
</tr>
<tr>
<td>Public</td>
<td>R</td>
<td>Internal</td>
</tr>
<tr>
<td>Public</td>
<td>T</td>
<td>Internal</td>
</tr>
<tr>
<td>Students</td>
<td>C</td>
<td>Internal</td>
</tr>
<tr>
<td>...</td>
<td>...</td>
<td>...</td>
</tr>
<tr>
<td>Administration</td>
<td>T</td>
<td>International</td>
</tr>
</tbody>
</table>

This data structure is commonly used in relational DBMSs
The choice of ACLs vs capability lists affects many aspects of the system:

- ACL systems need a namespace for both objects and subjects, while a capability ticket can serve both to designate a resource and to provide authority.

- Procedures such as access review and revocation are superior on a per-object basis in ACL systems and on per-subject basis in capability systems.

- ACL systems require authentication of subjects, while capability systems require unforgeability and control of propagation of capabilities.

Most real-world OSs use ACLs.
Discretionary Access Control

- **In mandatory access control (MAC)** users are granted privileges, which they cannot control or change.

- **Discretionary access control (DAC)** has provisions for allowing subjects to grant privileges to other subjects.
  - As a result, the access control matrix $A$ can change.

- Let triple $(s, o, a)$ represent an access right.

- At time $i$, the state $X_i$ of the system is characterized by $(S_i, O_i, A_i)$.

- **Transition** $t_i$ takes the system from state $X_i$ to $X_{i+1}$.
  - A single transition $X_i \vdash t_i X_{i+1}$.
  - Series of transitions $X \vdash^* Y$. 

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Discretionary Access Control

- The access control matrix can be extended to include different types of objects
  - the subjects themselves can also be objects
  - different types of objects can have different access operations defined for them
- e.g., stop and wakeup rights for processes, read and write access to memory, seek access to disk drives

- For simplicity assume that we are dealing with one type of objects

<table>
<thead>
<tr>
<th></th>
<th>$s_1$</th>
<th>$\cdots$</th>
<th>$s_n$</th>
<th>$o_1$</th>
<th>$\cdots$</th>
<th>$o_m$</th>
<th>$p_1$</th>
<th>$\cdots$</th>
<th>$p_\ell$</th>
</tr>
</thead>
<tbody>
<tr>
<td>$s_1$</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>$\cdots$</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>$s_n$</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

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Suppose we have the following access rights

- basic read and write
- own: possessor can change their own privileges
- copy or grant: possessor can extend its privileges to another subject
  - this is modeled by setting a copy flag on the access right
  - for example, right $r$ cannot be copied, but $r^*$ can

Grant right gives rise to the principle of attenuation of privilege:

- a subject may not give rights it does not possess

Each particular model has a set of rules that define acceptable modifications to the access control matrix
Discretionary Access Control

• **Primitive commands**
  
  – create object $o$ (with no access)
    
    - $S_{i+1} = S_i$, $O_{i+1} = O_i \cup \{o\}$, $\forall x \in S_{i+1}, A_{i+1}[x, o] = \emptyset$, $\forall x \in S_{i+1}, \forall y \in O_i, A_{i+1}[x, y] = A_i[x, y]$
  
  – create subject $s$ (with no access)
    
    - add $s$ to the set of subjects and objects, set relevant access to $\emptyset$
  
  – add right $r$ to object $o$ for subject $s$
    
    - $A_{i+1}[s, o] = A_i[s, o] \cup \{r\}$, everything else stays the same
  
  – delete right $r$ from $A_i[s, o]$
  
  – destroy subject $s$
  
  – destroy object $o$
• Building more useful commands

  – s creates object o
    • create object o with no access
    • add right own to object o for subject s

  – s adds right r to object o for subject s'
    • if (r* ∈ A_i[s, o] or own ∈ A_i[s, o]), then
      \[ A_{i+1}[s', o] = A_i[s', o] \cup \{r\} \]
    • leave the rest unchanged

  – s deletes object o
    • if (own ∈ A_i[s, o]), then remove all access rights ∀x ∈ S_i from
      A[x, o] and destroy o
Discretionary Access Control

- **Example:** suppose we initially have

<table>
<thead>
<tr>
<th></th>
<th>$s_1$</th>
<th>$s_2$</th>
<th>$o_1$</th>
<th>$o_2$</th>
<th>$o_3$</th>
</tr>
</thead>
<tbody>
<tr>
<td>$s_1$</td>
<td>own</td>
<td></td>
<td>own, read*</td>
<td>write</td>
<td>read, write</td>
</tr>
<tr>
<td>$s_2$</td>
<td></td>
<td>own</td>
<td>own, write</td>
<td></td>
<td>own</td>
</tr>
</tbody>
</table>

- subject $s_1$ creates $s_3$
- $s_1$ grants to $s_3$ *read* on $o_1$
- $s_3$ grants to $s_2$ *read* on $o_1$
- can $s_1$ revoke $s_2$’s right on $o_1$?

- Attenuation of privilege principle is usually ignored for the owner
  - why?
• Access control is enforced by the operating system

• Files
  – how is a file identified?
  – where are permissions stored?
  – is directory a file?

• Users
  – each user has a unique ID
  – each user is a member of a primary group (and possibly other groups)
• **Subjects** are processes acting on behalf of users
  – each process is associated with a uid/gid pair

• **Objects** are files and processes

• Each **file** has information about: owner, group, and 12 permission bits
  – read/write/execute for owner, group, and others
  – suid, sgid, and sticky

• Example

  ```
  user::rw-  
  group::r-- 
  other::---
  ```
DAC in Unix File System

- DAC is implemented by using commands `chmod` and `chown`.
- A special user “superuser” or “root” is exempt from regular access control constraints.
- Many Unix systems support additional ACLs:
  - Owner (or administrator) can add to a file users or groups with specific access privileges.
  - The permissions are specified per user or group as regular three permission bits.
  - `setfacl` and `getfacl` commands change and list ACLs.
- This is called extended ACL, while the traditional permission bits are called minimal ACL.
Security of Discretionary Access Control

• **What is secure in the context of DAC?**
  
  – a secure system doesn’t allow violations of policy
  
  – how can we use this definition?

• **Alternative definition based on rights**
  
  – start with access control matrix \( A \) that already includes all rights we want to have
  
  – a **leak** occurs if commands can add right \( r \) to an element of \( A \) not containing \( r \)
  
  – a system is **safe** with respect to \( r \) if \( r \) cannot be leaked
Safety of DAC Models

- Assume we have an access control matrix

<table>
<thead>
<tr>
<th></th>
<th>( f_a )</th>
<th>( f_b )</th>
<th>( f_c )</th>
</tr>
</thead>
<tbody>
<tr>
<td>( s_a )</td>
<td>own, ( r, w )</td>
<td>( r )</td>
<td>( r )</td>
</tr>
<tr>
<td>( s_b )</td>
<td>( r )</td>
<td>own, ( r, w )</td>
<td>( r )</td>
</tr>
<tr>
<td>( s_c )</td>
<td>( r )</td>
<td>( r )</td>
<td>own, ( r, w )</td>
</tr>
</tbody>
</table>

- is it safe with respect to \( r \)?
- is it safe with respect to \( w \)?
- what if we disallow granting rights? object deletion?

- Safety of many useful models is undecidable
  - safety of certain models is tractable, but they tend not to apply to real world
Decidability of DAC Models

● **Decidable**
  – we are given a system, where each command consists of a single primitive command
  – there exists an algorithm that will determine if the system with initial state $X_0$ is safe with respect to right $r$

● **Undecidable**
  – we are now given a system that has non-primitive commands
  – given a system state, it is undecidable if the system is safe for a given generic right
  – the safety problem can be reduced to the halting problem by simulating a Turing machine

● **Some other special DAC models can be decidable**
Does “safe” really mean secure?

Example: Unix file system

- root has access to all files
- owner has access to their own files
- is it safe with respect to file access right?
  - have to disallow chmod and chown commands
  - only “root” can get root privileges
  - only user can authenticate as themselves

Safety doesn’t distinguish a leak from authorized transfer of rights

- is this definition useful?
• **Solution is trust**
  
  – subjects authorized to receive transfer of rights are considered “trusted”
  
  – trusted subjects are eliminated from the access control matrix

• Also, safety only works if maximum rights are known in advance
  
  – policy must specify all rights someone could get, not just what they have
  
  – how applicable is this?

• And safety is still undecidable for practical models
Mandatory Access Control

• In mandatory access control (MAC) users are granted privileges, which they cannot control or change
  – useful for military applications
  – useful for regular operating systems

• DAC does not protect against
  – malware
  – software bugs
  – malicious local users

• DAC cannot control information flow
MAC in Operating Systems

- The need for MAC
  - host compromise by network-based attacks is the root cause of many serious security problems
    - worm, botnet, DDoS, phishing, spamming
  - hosts can be easily compromised
    - programs contain exploitable bugs
    - DAC mechanisms in OSs were not designed to take buggy software in mind
  - adding MAC to OSs is essential to deal with host compromise
    - last line of defense when everything else fails
- In MAC a system-wide security policy restricts access rights of subjects
Combining MAC and DAC

- It is common to combine mandatory and discretionary access control in complex systems
  - modern operating systems is one significant example

- MAC and DAC are also combined in older models that implement multilevel security (for military-style security classes)
  - Bell-Lapadula confidentiality model (1973)
  - Biba integrity model (1977)

- Related models for commercial applications include
  - Clark-Wilson model
  - Chinese Wall model
• Access control is central in providing an adequate level of security

• Access control rights can be specified in the form of
  – access control matrix
  – access control lists
  – capability tickets
  – access control tables

• Types of access control
  – already covered DAC and MAC
  – will look at role-based access control (RBAC) and attribute-based access control