LinuxCon North America 2012 (San Diego)

CaitSith

a new type of rule based in-kernel access control

Tetsuo Handa, NTT

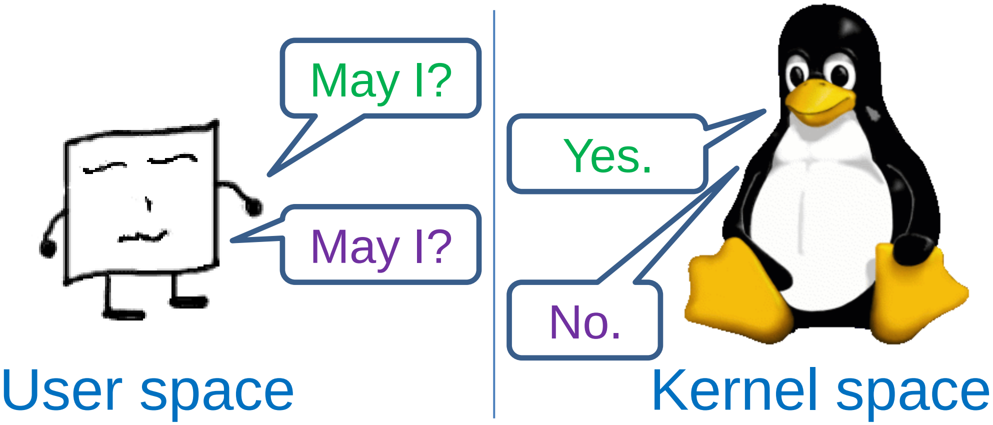
2012/8/29-2012/8/31

Who am I?

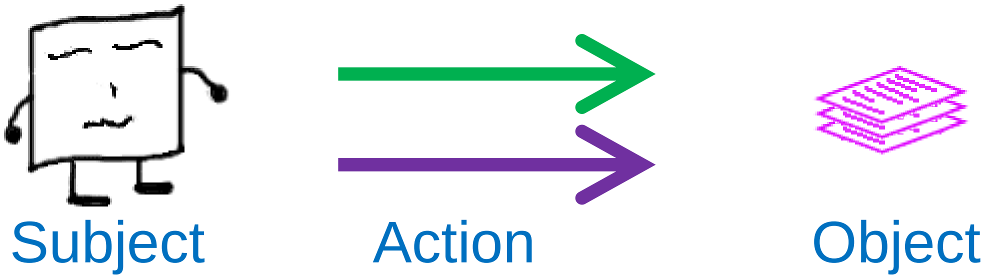
- A retired employed programmer
- My involvement with Linux
  - 2001.10-2003.3 Developing user space applications that run on Linux systems.
  - 2003.4-2012.3 Developing kernel mechanisms for improving security of Linux systems.
  - 2012.4- Providing user support service for troubleshooting Linux systems.

What do I speak today?

- Security, especially access control in kernel space.

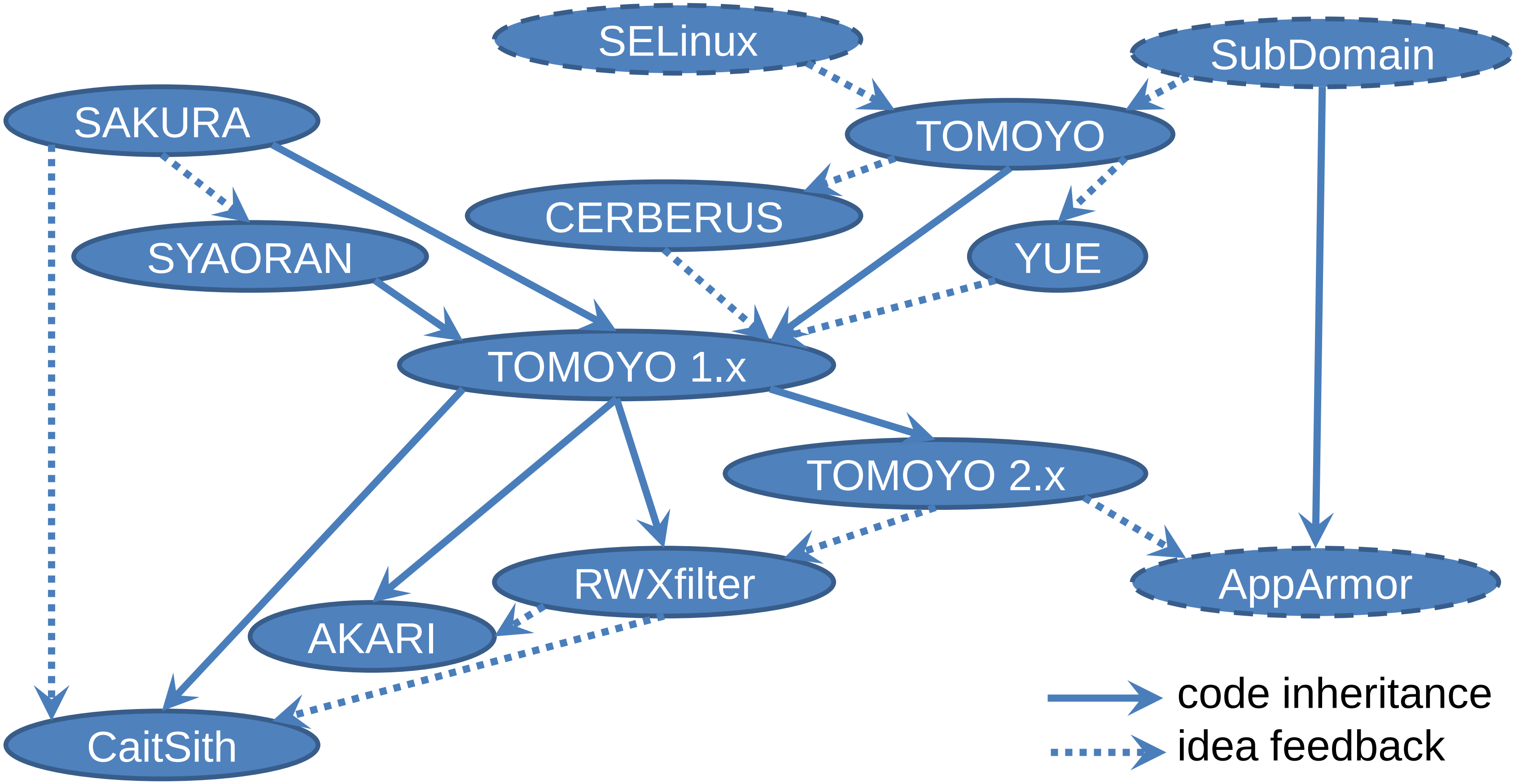


- Subject(processes), Action, Object(resources)
  - That's all. However, it is extremely difficult to develop rules that match user's needs.



Players?

- Security mechanisms which come on my talk.



TOMOYO is a registered trademark of NTT DATA CORPORATION in Japan.

Structure of this presentation?

- Chapter 1 --- Introduction: Summarized description of what has happened before CaitSith
  - For users who are interested in in-kernel access control.
- Chapter 2 --- Things I experienced with continuing enhancement of access control functionality
  - For developers who are developing access control modules.
- Chapter 3 --- Things I experienced with continuing enhancement of ease of use
  - For users who are seeking for simpler in-kernel access control modules.
- Chapter 4 --- CaitSith
  - For users who are interested in my proposal.

Chapter 1

Introduction: Summarized description of what has happened before CaitSith

Everyone's security varies?

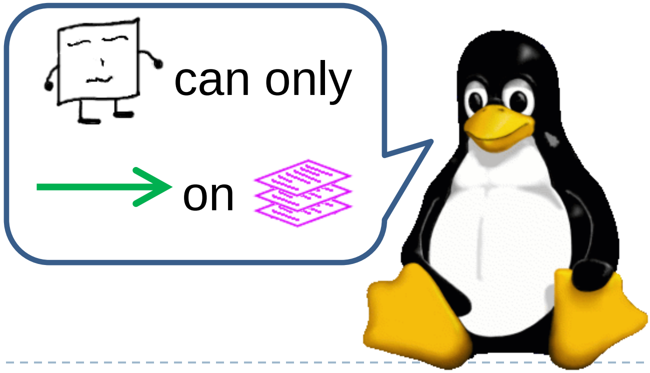
- What people associate with the word "security" depends on their skill levels and beliefs.
  - Give people choices, rather than forcing the only one.
- My belief is that visualization is important.
  - Many of today's security issues come from invisibleness.
  - Traceability leads to satisfaction.

Attempts for doing access control in the kernel space

- Threats are in the behavior of the user space.
- But, doing access control in the user space is problematic.
  - It can be bypassed when deprived of control.
  - Its level and granularity varies.
- Let's do access control in the kernel space, in addition to access control in the user space.
  - Although what in-kernel access control can do is limited, in-kernel access control can provide a baseline restriction and will be useful.

Mandatory Access Control(MAC)

- Implementation that does access control in the kernel space.
  - It cannot be bypassed because it is done in the kernel space.
- Currently, SELinux, SMACK, TOMOYO and AppArmor are in the Linux mainline kernel.
  - They are all **whitelisting** approach which uses Linux Security Modules (LSM) interface.
  - They do access control from the point of view of **subjects**.



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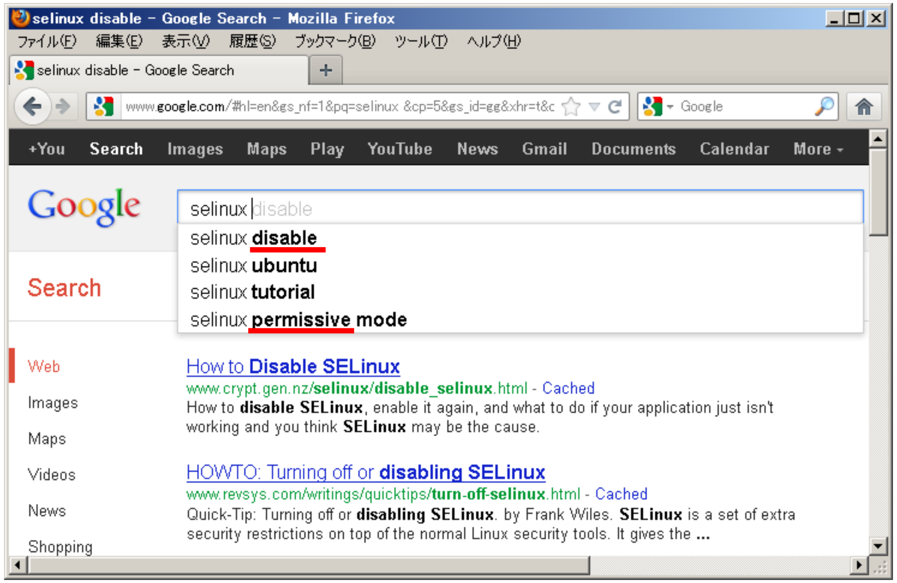
Distributor's kernels enable some of them, but...

- Many people are still disabling SELinux.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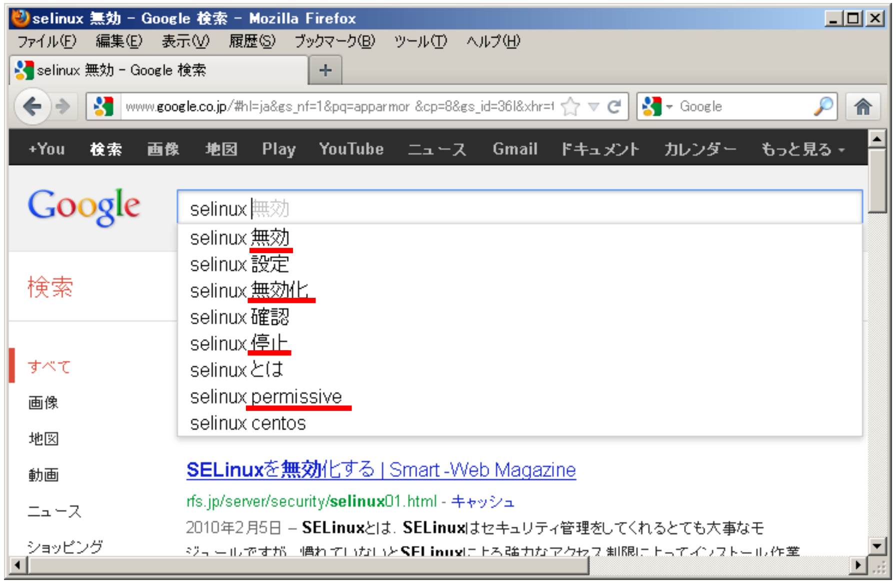
selinux **tutorial**
selinux **permissive mode**

How to **Disable SELinux**
www.crypt.gen.nz/**selinux/disable_selinux**.html - Cached
How to **disable SELinux**, enable it again, and what to do if your application just isn't working and you think **SELinux** may be the cause.

HOWTO: Turning off or **disabling SELinux**
www.revsys.com/writings/quicktips/**turn-off-selinux**.html - Cached
Quick-Tip: Turning off or **disabling SELinux**. by Frank Wiles. **SELinux** is a set of extra security restrictions on top of the normal Linux security tools. It gives the ...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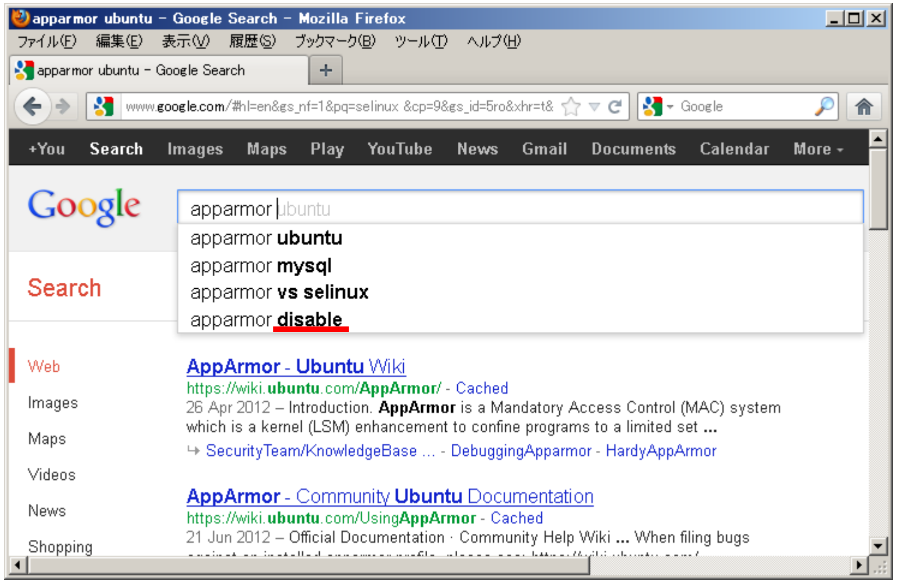
selinux 無効

selinux 無効
selinux 設定
selinux 無効化
selinux 確認
selinux 停止
selinux とは
selinux permissive
selinux centos

SELinuxを**無効**化する | Smart -Web Magazine
rfs.jp/server/security/**selinux**01.html - キャッシュ
2010年2月5日 – **SELinux**とは. **SELinux**はセキュリティ管理をしてくれるとても大事なモジュールですが、慣れていないと**SELinux**による強力なアクセス制限によってインストール作業

Distributor's kernels enable some of them, but...

- Even AppArmor which was claimed to be easier than SELinux is disabled.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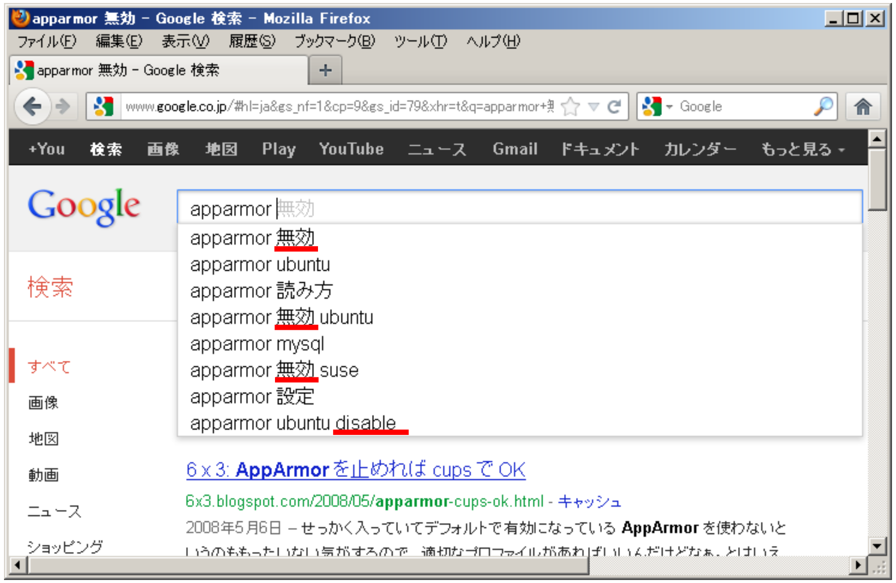
apparmor **ubuntu**
apparmor **mysql**
apparmor **vs selinux**
apparmor **disable**

AppArmor - Ubuntu Wiki
https://wiki.ubuntu.com/AppArmor/ - Cached
26 Apr 2012 – Introduction. **AppArmor** is a Mandatory Access Control (MAC) system which is a kernel (LSM) enhancement to confine programs to a limited set ...
↳ SecurityTeam/KnowledgeBase ... - DebuggingApparmor - HardyAppArmor

AppArmor - Community Ubuntu Documentation
https://wiki.ubuntu.com/UsingAppArmor - Cached
21 Jun 2012 – Official Documentation · Community Help Wiki ... When filing bugs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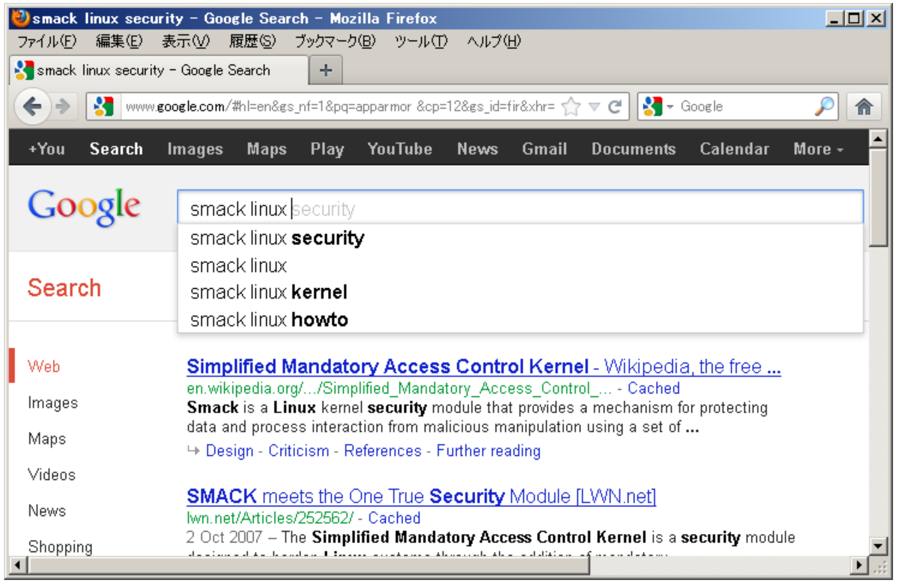
6 x 3: **AppArmor** を止めれば cups で OK
6x3.blogspot.com/2008/05/**apparmor**-cups-ok.html - キャッシュ
2008年5月6日 – せっかく入っていてデフォルトで有効になっている **AppArmor** を使わないと
いうのももったいない気がするので、適切なプロファイルがあればいいんだけどなぁ。とはいえ

Distributor's kernels enable some of them, but...

- What about SMACK?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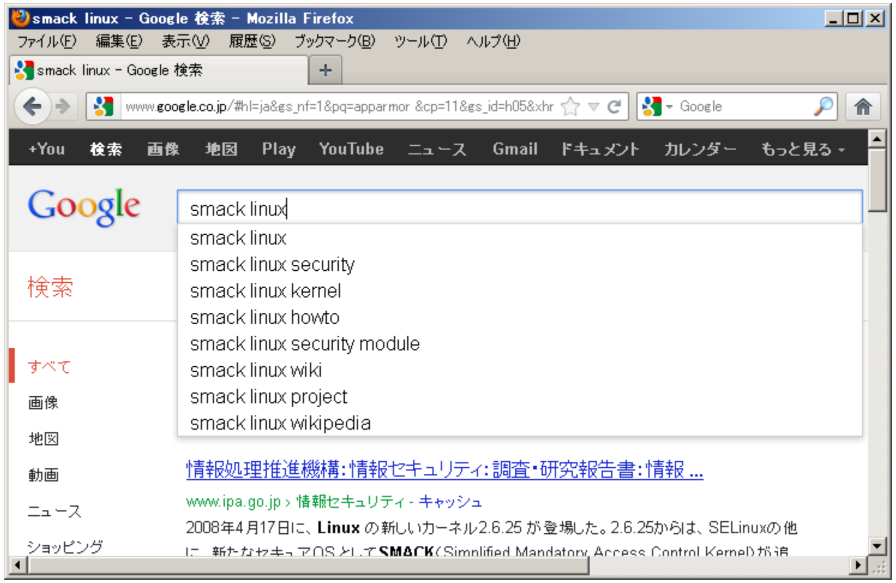
Simplified Mandatory Access Control Kernel - Wikipedia, the free ...
en.wikipedia.org/.../Simplified_Mandatory_Access_Control_... - Cached
Smack is a **Linux** kernel **security** module that provides a mechanism for protecting data and process interaction from malicious manipulation using a set of ...
↳ Design - Criticism - References - Further reading

SMACK meets the One True **Security** Module [LWN.net]
lwn.net/Articles/252562/ - Cached
2 Oct 2007 – The **Simplified Mandatory Access Control Kernel** is a **security** module designed to harden **Linux** systems through the addition of mandatory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smack linux project
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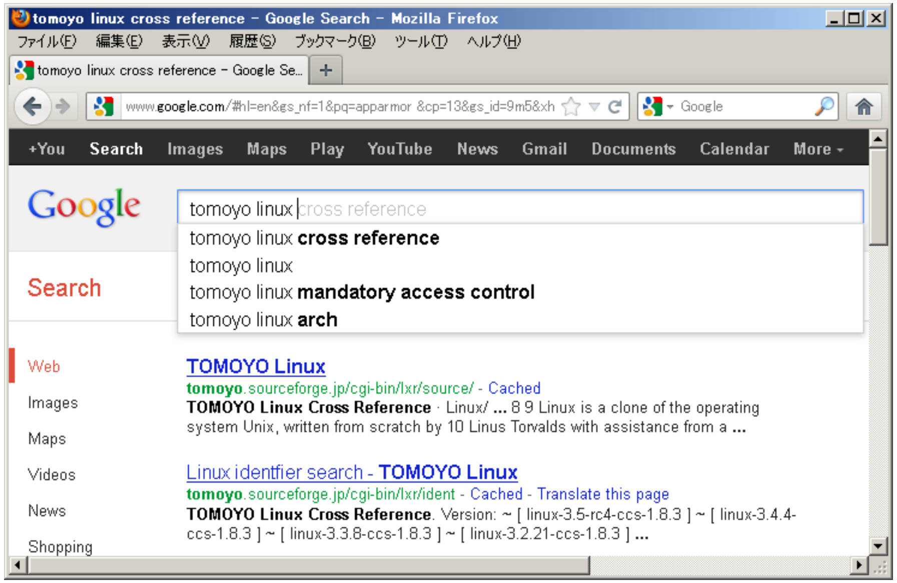
情報処理推進機構:情報セキュリティ:調査・研究報告書:情報 ...
www.ipa.go.jp › 情報セキュリティ - キャッシュ
2008年4月17日に、**Linux** の新しいカーネル2.6.25 が登場した。2.6.25からは、SELinuxの他に、新たなセキュアOSとして**SMACK**(Simplified Mandatory Access Control Kernel)が追

- Not disabled yet, for SMACK is not enabled without user's explicit configuration.

Distributor's kernels enable some of them, but...

- What about TOMOYO?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tomoyo linux **arch**

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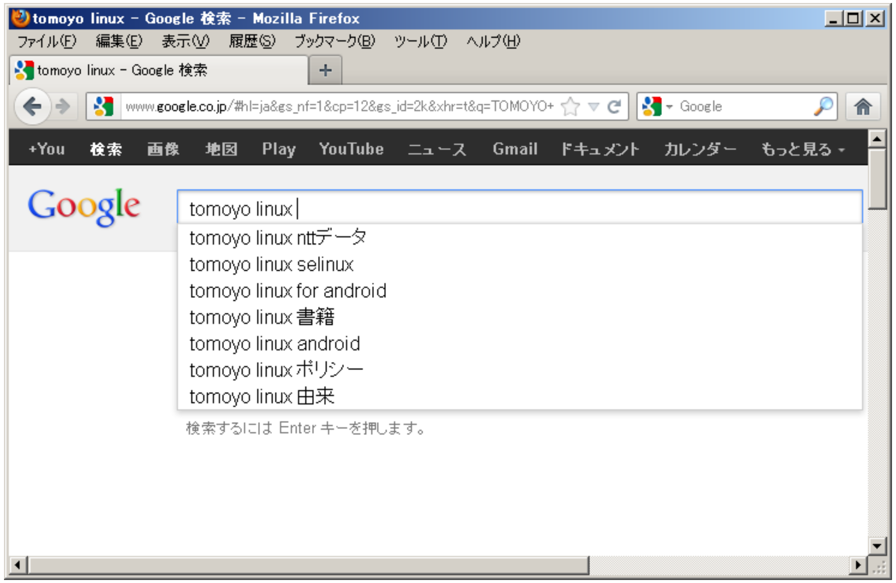
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検索するには Enter キーを押します。

- Not disabled yet, for TOMOYO is not enabled without user's explicit configuration.

Distributor's kernels enable some of them, but...

- Reasons to disable them?
  - Fears to use without understanding their configuration.
  - Fears to miss permissions in the whitelisting approach.
- There are a lot of documentation.
  - Too long, didn't read.
  - They are for developers, not for users.

"all or nothing" problem

- Ideally, access control is enforced on all subjects and all objects.

- In reality, it is considered as "Well done" if access control is enforced on some specific subjects.

- When troubles occur, they will have no choice but to **disable entirely** unless they know how to configure policy and current policy configurations.

Reasons why TOMOYO insisted on manageability for users?

- No resource to distribute ready-made policy.
  - TOMOYO has no background distributors compared to SELinux(RedHat) and AppArmor(SUSE/Ubuntu).
- Unable to troubleshoot if ready-made policy is used.
  - TOMOYO would follow the same way where SELinux and AppArmor stray into.
- What people want to allow/deny varies.
  - It is impossible to develop ready-made policy that can cover everybody's needs.
- Have to disable upon troubles if there is only one switch.
  - "all or nothing" problem

Problems with developing policy configuration

- An "access control" restricts access requests based on rules defined beforehand.
  - It is an implicit requirement that users can define rules beforehand.
  - However, to define rules beforehand, users have to be familiar with internal structure of Linux systems.
  - Not many users are familiar with Linux internal because it is a world where they usually don't care.
- However, paying attention for burden of defining rules has generally been viewed as unimportant.
  - TOMOYO had been paying attention for this burden.

TOMOYO had been struggled in order to keep TOMOYO enabled.

- Made possible to enable/disable on a per-action basis using profiles.
  - This allows users to choose the action coverage based on their skills.
- Made possible to enable/disable on a per-domain basis using profiles.
  - This allows users to choose the subjects coverage based on their skills.

TOMOYO had been struggled in order to keep TOMOYO enabled.

- Made possible to handle policy violations interactively.
  - This allows users to judge unexpected access requests on a case-by-case basis.
- Made possible to understand all states using tree style domain transitions.
  - This allows users to understand what's going on.

Meanwhile, I received unexpected requests from RHEL users...

- "I want to apply access control on specific resources (files), rather than applying on specific processes."
  - TOMOYO was allowing users to enable/disable access control on a per-action basis and a per-domain basis, but was not allowing users to enable/disable access control on a per-file basis.

After all, did existing MAC implementations respond to user's needs?

- User's needs are not always whitelisting nor from the point of view of processes.
  - Some wants to apply from the point of view of resources.
  - Some are not interested in managing domains.
  - These are limitations for TOMOYO.

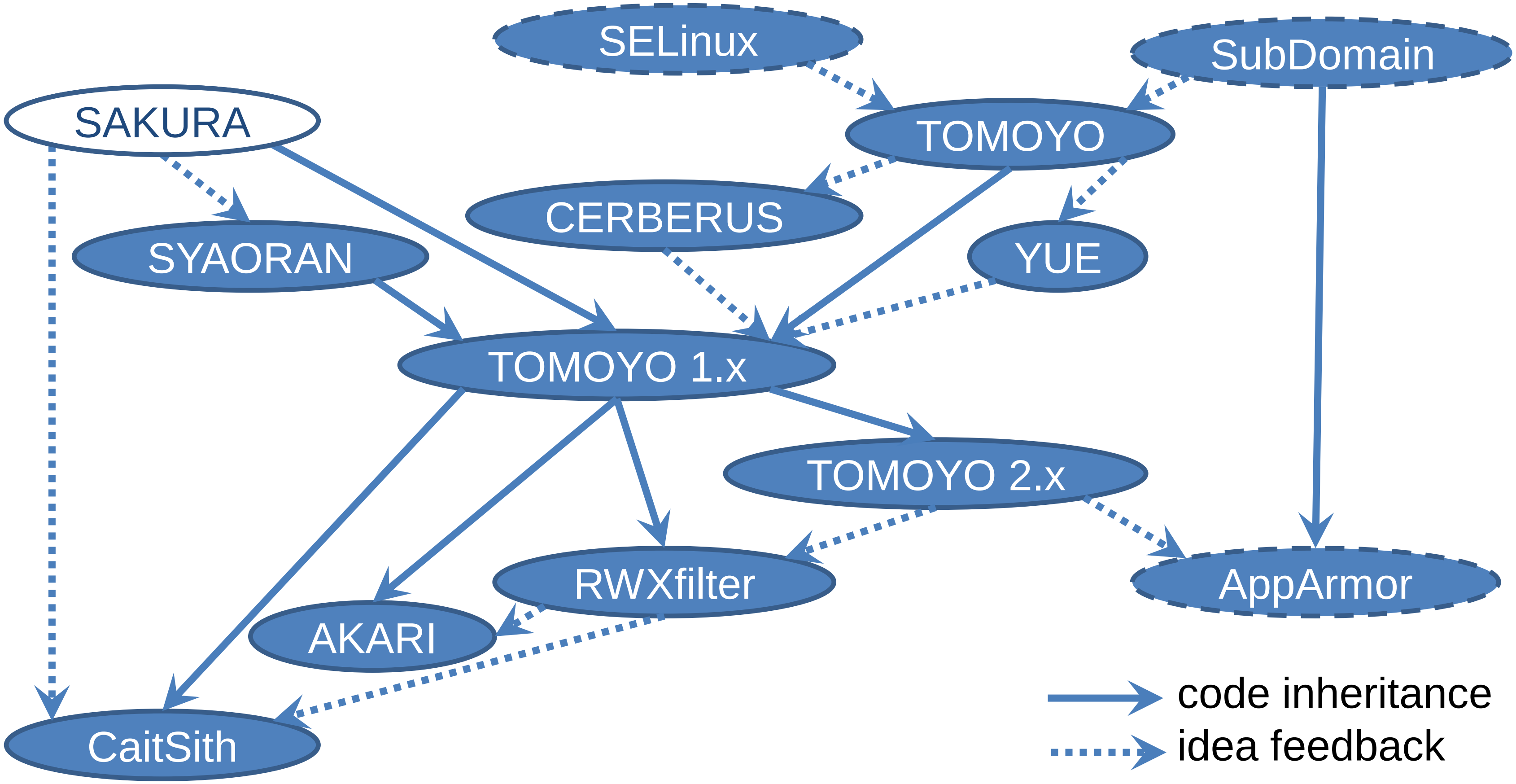
- We might want to try a fundamental course-changing move.
  - That's the trigger for developing CaitSith.

Chapter 2

Things I experienced with continuing enhancement of access control functionality

SAKURA (2003.4-)

- An attempt for protecting Linux systems without policy management.



SAKURA

- I tried SELinux, but I soon gave up because SELinux was too difficult to use.
  - Can't we omit policy management by specializing for protection from tampering?
- Code name: "Security Advancement Know-how Upon Read-only Approach for Linux"
- Topics on SAKURA
  - Protection from tampering via read-only mounting
  - System-wide access restriction
  - Spontaneous permission abandonment via modification of user space programs

Protection from tampering via read-only mounting

- Mounting filesystems as read-only wherever possible in order to reduce the risk of tampering files.
  - I modified the kernel to report pathnames which failed with -EROFS error in order to help separating read-only directories and writable directories.
  - Mount all partitions except partitions which need to be writable (e.g. /var and /tmp) read-only, and store read-only partitions into read-only medium in order to protect from direct tampering attacks (e.g. writing to block device files which corresponds to read-only mounted partitions).

System-wide access restriction

- Mounting a writable filesystem over a read-only filesystem ruins tamper-proof protection.
  - Restrict namespace related actions (e.g. mount, chroot, pivot_root) for system-wide.
  - An example configuration looks like below.

```
allow_mount devpts /dev/pts/ devpts 0x0
allow_mount any / --remount 0x0
allow_mount securityfs /sys/kernel/security/ securityfs 0x0
allow_mount none /proc/sys/fs/binfmt_misc/ binfmt_misc 0x0
allow_chroot /etc/avahi/
allow_chroot /var/empty/sshd/
```

Note that the name of processes are not specified.

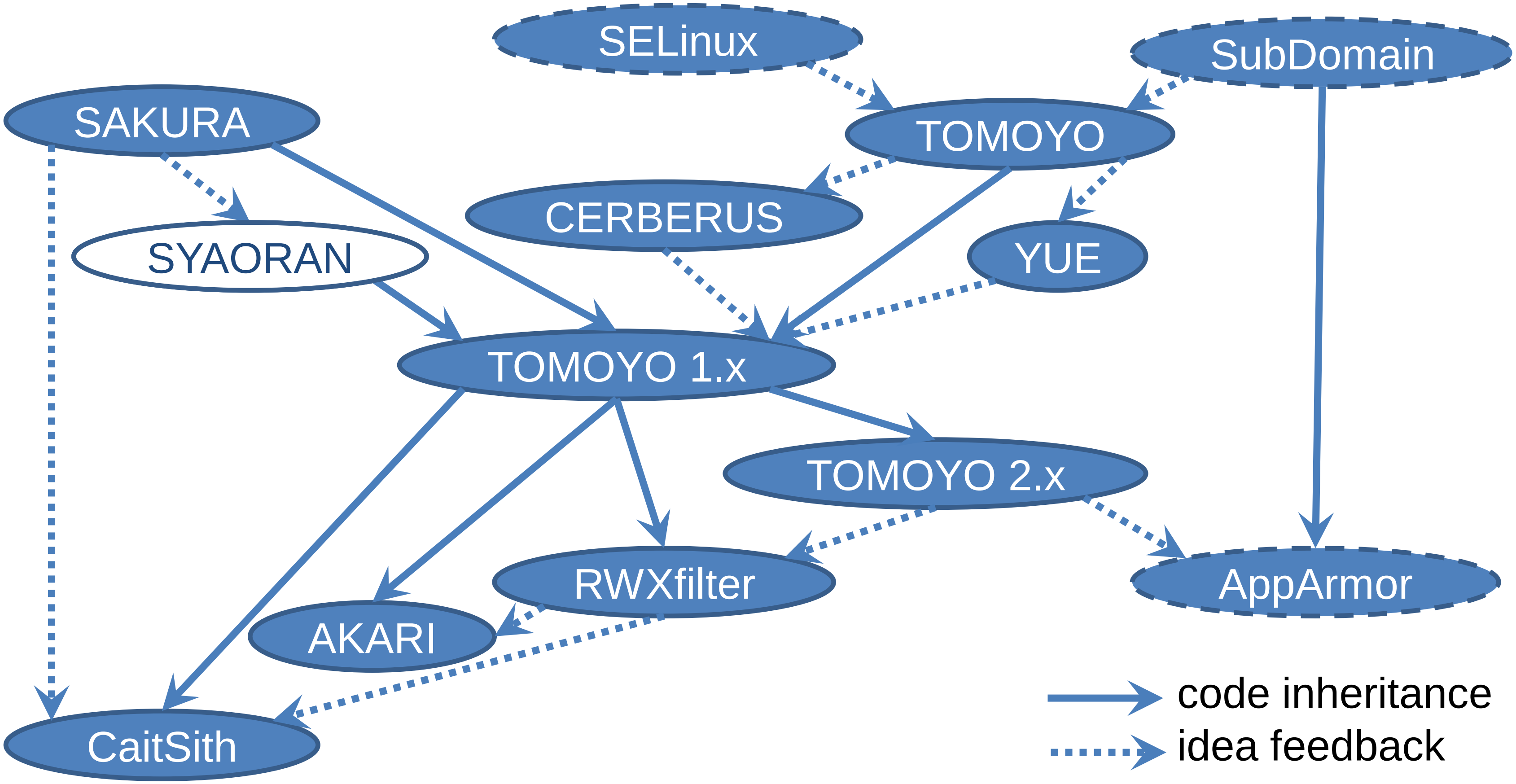
Spontaneous permission abandonment via modification of user space programs

- To make system-wide access restriction more efficient, I added spontaneous permission abandonment by appending a original field to task_struct of Linux 2.4 kernels.
  - Allow user space programs to discard permissions to call execve(), chroot(), pivot_root(), mount() and a permission to regain effective UID = 0 on a per-task_struct basis.
    - Temporal discard which the permissions will be regained after successful execve() request.
    - Permanent discard which the permissions will not be regained after execve() request.
- We could not afford resource to modify user space programs and this feature was removed in TOMOYO 1.4.

  => But a more wider spontaneous permission abandonment feature was added to Linux 3.5 as "seccomp mode 2".

SYAORAN (2004.10-)

- Tamper-proof filesystem for /dev partition.



SYAORAN

- SAKURA made it possible to mount / partition as read-only, but /dev cannot be mounted as read-only.
  - Existing /dev filesystems (e.g. devfs and devtmpfs) allowed modification of directory entries via requests from user space.
  - Tampering files in /dev partition is a severe problem.
    - What happens if /dev/null has attributes of /dev/zero ?
- Code name: "Simple Yet All-important Object Realizing Abiding Nexus"
- Topics on SYAORAN
  - Tamper-proof filesystem for /dev partition

Tamper-proof filesystem for /dev partition

- I developed a dedicated filesystem for /dev by adding attribute checking logic to tmpfs filesystem.
  - By using this filesystem, we can enforce combination of filenames and their attributes.
  - For example, /dev/null always has char-1-3 and /dev/zero always has char-1-5.

Tamper-proof filesystem for /dev partition

- Configuration file looks like below.

```
#filename   perm owner group  flags   type   major   minor
pts          755     0      0      0      d
shm          755     0      0      0      d
null         666     0      0      0      c       1       3
zero         666     0      0      0      c       1       5
random       644     0      0      0      c       1       8
urandom      644     0      0      0      c       1       9
tty          666     0      0      0      c       5       0
tty0         600     0      0     12      c       4       0
tty1         600     0      0     12      c       4       1
```

Note that the permitted actions
(create/delete/chmod/chown/chgrp) are restricted

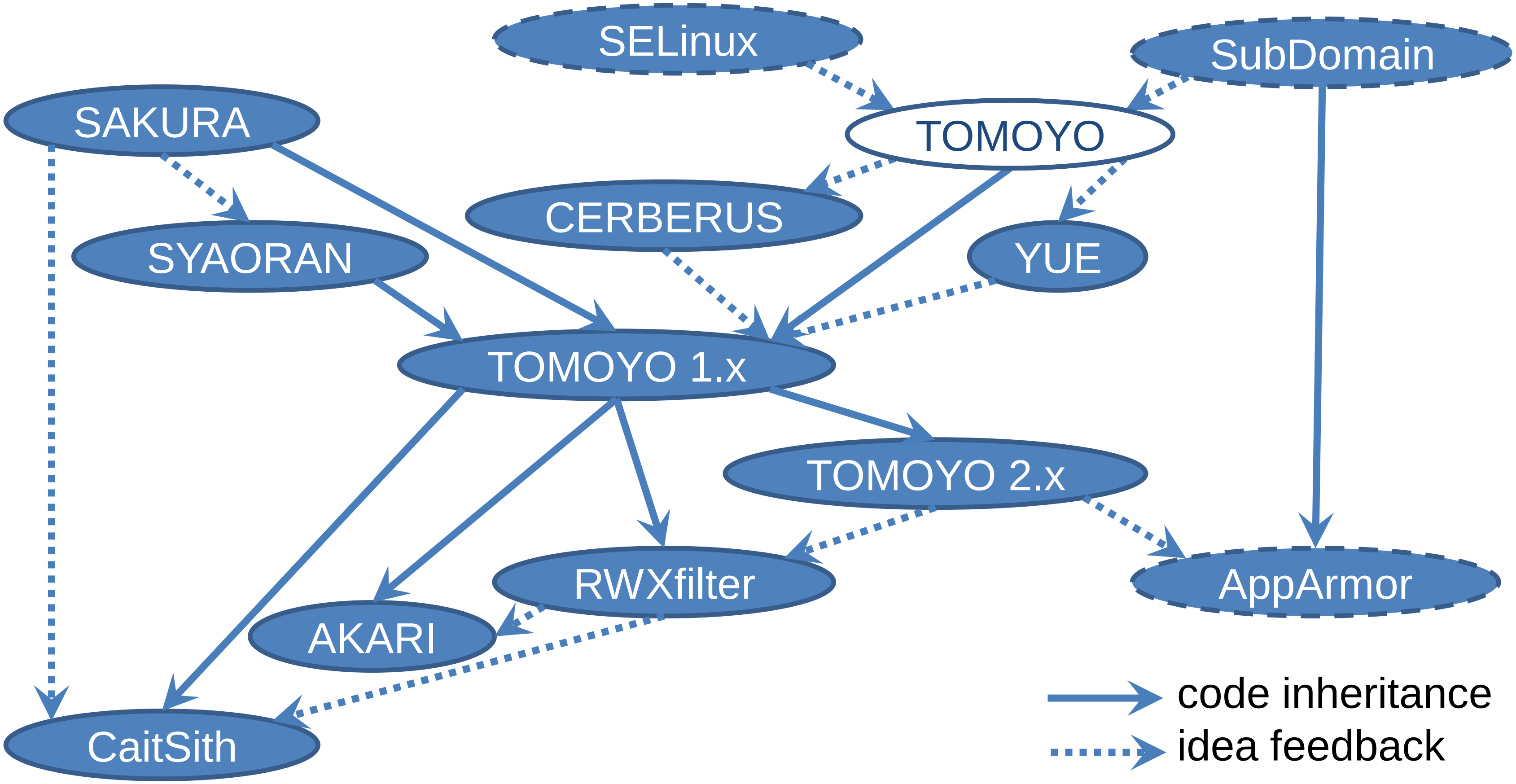
Managing policy is inevitable?

- By using SYAORAN for /dev and using SAKURA for wherever possible, the risk of tampering files can be reduced.
  - Although the combination of SAKURA and SYAORAN made it impossible to tamper files stored into read-only medium, storing into read-only medium also makes it impossible to handle software updates.
  - To make it possible to handle software updates while protecting from tampering, we should consider also using policy based protection.

=> Leads to TOMOYO.

TOMOYO (2003.7-)

- An attempt for implementing manageable policy.

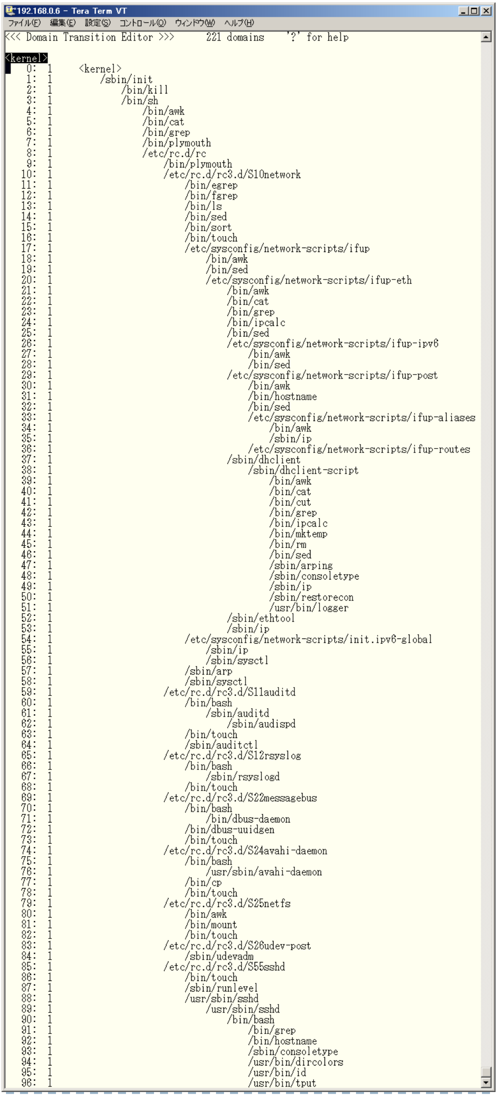


TOMOYO

- SELinux's policy is too difficult to use. Can't we develop original policy that covers only what we need?
  - Let's generate policy that allows only behavior of processes which we ever observed.
- Code name: "Task Oriented Management Obviates Your Onus on Linux"
- Topics on TOMOYO
  - System-wide domain transition tracing function
  - Access request tracing function on a per-domain basis
  - Access request restricting function on a per-domain basis

System-wide domain transition tracing function

- Append a original field to task_struct of Linux 2.4 kernels.
    - Form a tree style state transition using the fork()/execve() mechanism.
        - Use each state in the tree as a domain.



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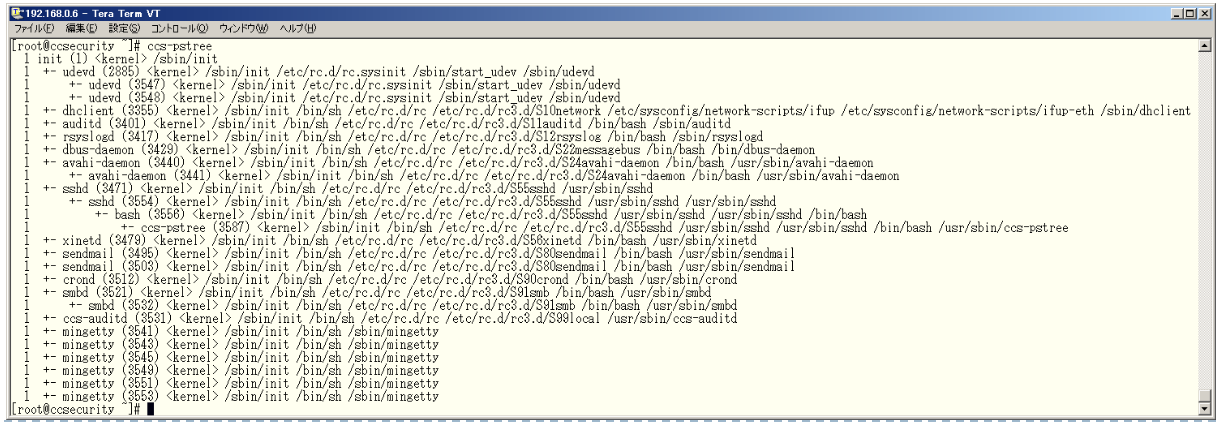
```
<<< Domain Transition Editor >>>      221 domains    '?' for help

<kernel>
   0:  1      <kernel>
   1:  1          /sbin/init
   2:  1              /bin/kill
   3:  1              /bin/sh
   4:  1                  /bin/awk
   5:  1                  /bin/cat
   6:  1                  /bin/grep
   7:  1                  /bin/plymouth
   8:  1                  /etc/rc.d/rc
   9:  1                      /bin/plymouth
  10:  1                      /etc/rc.d/rc3.d/S10network
  11:  1                          /bin/egrep
  12:  1                          /bin/fgrep
  13:  1                          /bin/ls
  14:  1                          /bin/sed
  15:  1                          /bin/sort
  16:  1                          /bin/touch
  17:  1                          /etc/sysconfig/network-scripts/ifup
  18:  1                              /bin/awk
  19:  1                              /bin/sed
  20:  1                              /etc/sysconfig/network-scripts/ifup-eth
  21:  1                                  /bin/awk
  22:  1                                  /bin/cat
  23:  1                                  /bin/grep
  24:  1                                  /bin/ipcalc
  25:  1                                  /bin/sed
  26:  1                                  /etc/sysconfig/network-scripts/ifup-ipv6
  27:  1                                      /bin/awk
  28:  1                                      /bin/sed
  29:  1                                  /etc/sysconfig/network-scripts/ifup-post
  30:  1                                      /bin/awk
  31:  1                                      /bin/hostname
  32:  1                                      /bin/sed
  33:  1                                      /etc/sysconfig/network-scripts/ifup-aliases
  34:  1                                          /bin/awk
  35:  1                                          /sbin/ip
  36:  1                                      /etc/sysconfig/network-scripts/ifup-routes
  37:  1                                  /sbin/dhclient
  38:  1                                      /sbin/dhclient-script
  39:  1                                          /bin/awk
  40:  1                                          /bin/cat
  41:  1                                          /bin/cut
  42:  1                                          /bin/grep
  43:  1                                          /bin/ipcalc
  44:  1                                          /bin/mktemp
  45:  1                                          /bin/rm
  46:  1                                          /bin/sed
  47:  1                                          /sbin/arping
  48:  1                                          /sbin/consoletype
  49:  1                                          /sbin/ip
  50:  1                                          /sbin/restorecon
  51:  1                                          /usr/bin/logger
  52:  1                                  /sbin/ethtool
  53:  1                                  /sbin/ip
  54:  1                          /etc/sysconfig/network-scripts/init.ipv6-global
  55:  1                              /sbin/ip
  56:  1                              /sbin/sysctl
  57:  1                          /sbin/arp
  58:  1                          /sbin/sysctl
  59:  1                      /etc/rc.d/rc3.d/S11auditd
  60:  1                          /bin/bash
  61:  1                              /sbin/auditd
  62:  1                                  /sbin/audispd
  63:  1                          /bin/touch
  64:  1                          /sbin/auditctl
  65:  1                      /etc/rc.d/rc3.d/S12rsyslog
  66:  1                          /bin/bash
  67:  1                              /sbin/rsyslogd
  68:  1                          /bin/touch
  69:  1                      /etc/rc.d/rc3.d/S22messagebus
  70:  1                          /bin/bash
  71:  1                              /bin/dbus-daemon
  72:  1                          /bin/dbus-uuidgen
  73:  1                          /bin/touch
  74:  1                      /etc/rc.d/rc3.d/S24avahi-daemon
  75:  1                          /bin/bash
  76:  1                              /usr/sbin/avahi-daemon
  77:  1                          /bin/cp
  78:  1                          /bin/touch
  79:  1                      /etc/rc.d/rc3.d/S25netfs
  80:  1                          /bin/awk
  81:  1                          /bin/mount
  82:  1                          /bin/touch
  83:  1                      /etc/rc.d/rc3.d/S26udev-post
  84:  1                          /sbin/udevadm
  85:  1                      /etc/rc.d/rc3.d/S55sshd
  86:  1                          /bin/touch
  87:  1                          /sbin/runlevel
  88:  1                          /usr/sbin/sshd
  89:  1                              /usr/sbin/sshd
  90:  1                                  /bin/bash
  91:  1                                      /bin/grep
  92:  1                                      /bin/hostname
  93:  1                                      /sbin/consoletype
  94:  1                                      /usr/bin/dircolors
  95:  1                                      /usr/bin/id
  96:  1                                      /usr/bin/tput
```

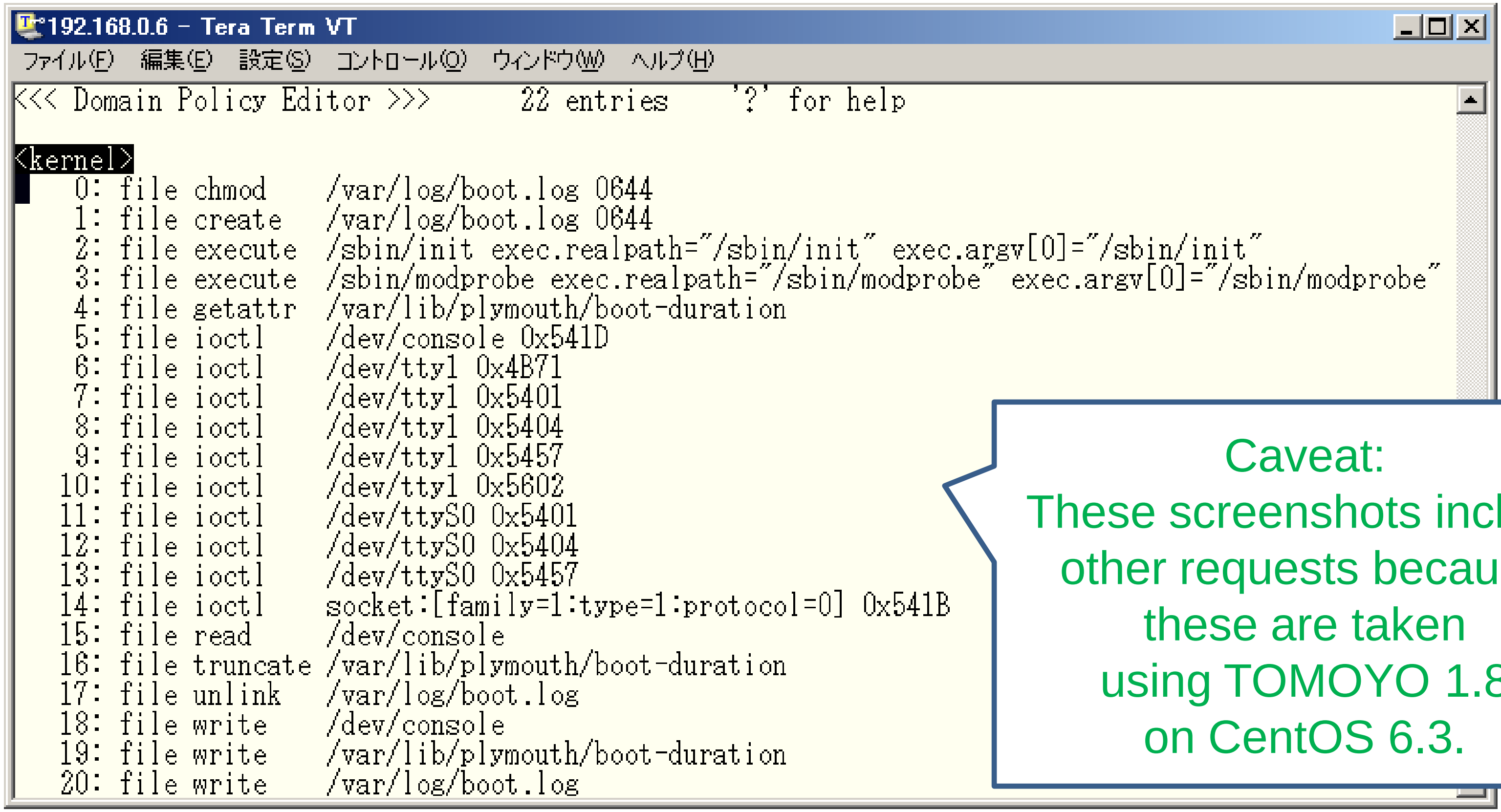


192.168.0.6 - Tera Term VT
ファイル(F) 編集(E) 設定(S) コントロール(O) ウィンドウ(W) ヘルプ(H)

```
[root@ccsecurity ~]# ccs-pstree
  1 init (1) <kernel> /sbin/init
  1  +- udevd (2885) <kernel> /sbin/init /etc/rc.d/rc.sysinit /sbin/start_udev /sbin/udevd
  1      +- udevd (3547) <kernel> /sbin/init /etc/rc.d/rc.sysinit /sbin/start_udev /sbin/udevd
  1      +- udevd (3548) <kernel> /sbin/init /etc/rc.d/rc.sysinit /sbin/start_udev /sbin/udevd
  1  +- dhclient (3355) <kernel> /sbin/init /bin/sh /etc/rc.d/rc /etc/rc.d/rc3.d/S10network /etc/sysconfig/network-scripts/ifup /etc/sysconfig/network-scripts/ifup-eth /sbin/dhclient
  1  +- auditd (3401) <kernel> /sbin/init /bin/sh /etc/rc.d/rc /etc/rc.d/rc3.d/S11auditd /bin/bash /sbin/auditd
  1  +- rsyslogd (3417) <kernel> /sbin/init /bin/sh /etc/rc.d/rc /etc/rc.d/rc3.d/S12rsyslog /bin/bash /sbin/rsyslogd
  1  +- dbus-daemon (3429) <kernel> /sbin/init /bin/sh /etc/rc.d/rc /etc/rc.d/rc3.d/S22messagebus /bin/bash /bin/dbus-daemon
  1  +- avahi-daemon (3440) <kernel> /sbin/init /bin/sh /etc/rc.d/rc /etc/rc.d/rc3.d/S24avahi-daemon /bin/bash /usr/sbin/avahi-daemon
  1      +- avahi-daemon (3441) <kernel> /sbin/init /bin/sh /etc/rc.d/rc /etc/rc.d/rc3.d/S24avahi-daemon /bin/bash /usr/sbin/avahi-daemon
  1  +- sshd (3471) <kernel> /sbin/init /bin/sh /etc/rc.d/rc /etc/rc.d/rc3.d/S55sshd /usr/sbin/sshd
  1      +- sshd (3554) <kernel> /sbin/init /bin/sh /etc/rc.d/rc /etc/rc.d/rc3.d/S55sshd /usr/sbin/sshd /usr/sbin/sshd
  1          +- bash (3556) <kernel> /sbin/init /bin/sh /etc/rc.d/rc /etc/rc.d/rc3.d/S55sshd /usr/sbin/sshd /usr/sbin/sshd /bin/bash
  1              +- ccs-pstree (3587) <kernel> /sbin/init /bin/sh /etc/rc.d/rc /etc/rc.d/rc3.d/S55sshd /usr/sbin/sshd /usr/sbin/sshd /bin/bash /usr/sbin/ccs-pstree
  1  +- xinetd (3479) <kernel> /sbin/init /bin/sh /etc/rc.d/rc /etc/rc.d/rc3.d/S56xinetd /bin/bash /usr/sbin/xinetd
  1  +- sendmail (3495) <kernel> /sbin/init /bin/sh /etc/rc.d/rc /etc/rc.d/rc3.d/S80sendmail /bin/bash /usr/sbin/sendmail
  1  +- sendmail (3503) <kernel> /sbin/init /bin/sh /etc/rc.d/rc /etc/rc.d/rc3.d/S80sendmail /bin/bash /usr/sbin/sendmail
  1  +- crond (3512) <kernel> /sbin/init /bin/sh /etc/rc.d/rc /etc/rc.d/rc3.d/S90crond /bin/bash /usr/sbin/crond
  1  +- smbd (3521) <kernel> /sbin/init /bin/sh /etc/rc.d/rc /etc/rc.d/rc3.d/S91smb /bin/bash /usr/sbin/smbd
  1      +- smbd (3532) <kernel> /sbin/init /bin/sh /etc/rc.d/rc /etc/rc.d/rc3.d/S91smb /bin/bash /usr/sbin/smbd
  1  +- ccs-auditd (3531) <kernel> /sbin/init /bin/sh /etc/rc.d/rc /etc/rc.d/rc3.d/S99local /usr/sbin/ccs-auditd
  1  +- mingetty (3541) <kernel> /sbin/init /bin/sh /sbin/mingetty
  1  +- mingetty (3543) <kernel> /sbin/init /bin/sh /sbin/mingetty
  1  +- mingetty (3545) <kernel> /sbin/init /bin/sh /sbin/mingetty
  1  +- mingetty (3549) <kernel> /sbin/init /bin/sh /sbin/mingetty
  1  +- mingetty (3551) <kernel> /sbin/init /bin/sh /sbin/mingetty
  1  +- mingetty (3553) <kernel> /sbin/init /bin/sh /sbin/mingetty
[root@ccsecurity ~]# █
```

Access request tracing function on a per-domain basis

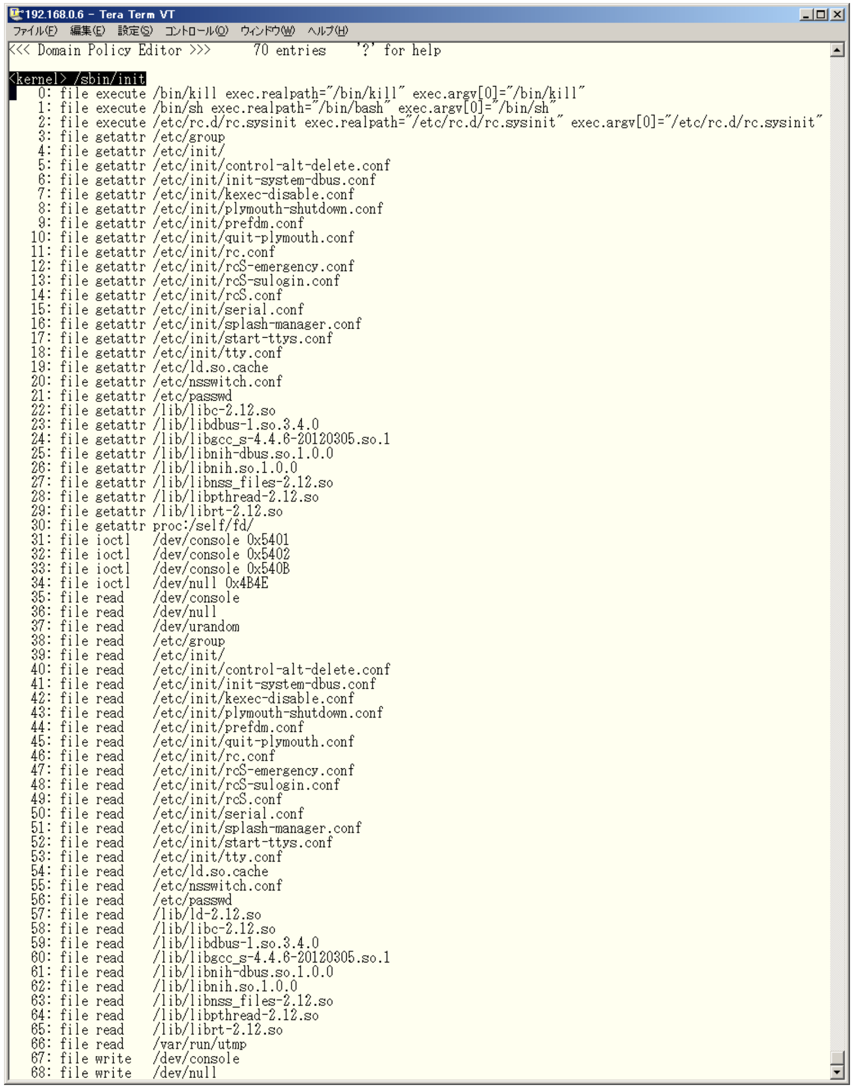
- Started as an access analysis tool.
  - Trace open() and execve() requests using pathnames and sort the output by domain as a key.


192.168.0.6 - Tera Term VT
ファイル(F) 編集(E) 設定(S) コントロール(O) ウィンドウ(W) ヘルプ(H)

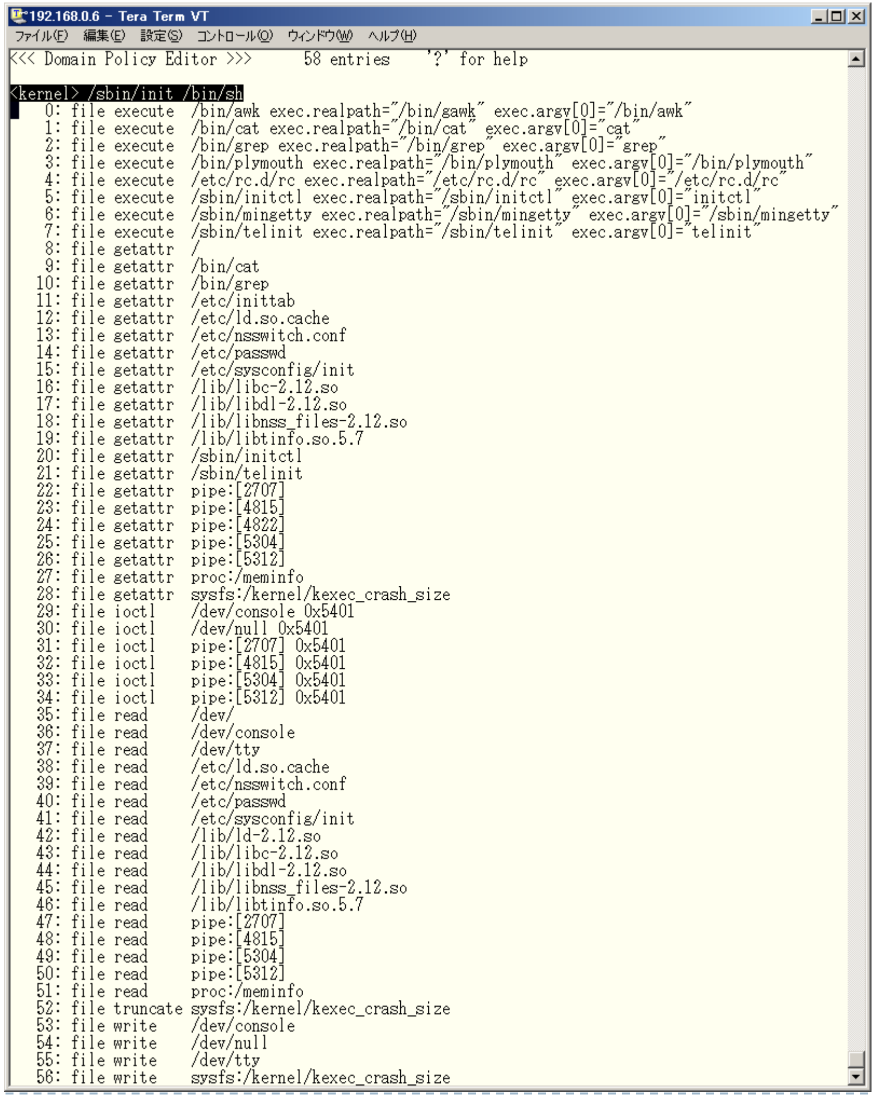
```
<<< Domain Policy Editor >>>      22 entries    '?' for help

<kernel>
    0: file chmod    /var/log/boot.log 0644
    1: file create   /var/log/boot.log 0644
    2: file execute  /sbin/init exec.realpath="/sbin/init" exec.argv[0]="/sbin/init"
    3: file execute  /sbin/modprobe exec.realpath="/sbin/modprobe" exec.argv[0]="/sbin/modprobe"
    4: file getattr  /var/lib/plymouth/boot-duration
    5: file ioctl    /dev/console 0x541D
    6: file ioctl    /dev/tty1 0x4B71
    7: file ioctl    /dev/tty1 0x5401
    8: file ioctl    /dev/tty1 0x5404
    9: file ioctl    /dev/tty1 0x5457
   10: file ioctl    /dev/tty1 0x5602
   11: file ioctl    /dev/ttyS0 0x5401
   12: file ioctl    /dev/ttyS0 0x5404
   13: file ioctl    /dev/ttyS0 0x5457
   14: file ioctl    socket:[family=1:type=1:protocol=0] 0x541B
   15: file read     /dev/console
   16: file truncate /var/lib/plymouth/boot-duration
   17: file unlink   /var/log/boot.log
   18: file write    /dev/console
   19: file write    /var/lib/plymouth/boot-duration
   20: file write    /var/log/boot.log
```

Caveat:
These screenshots include other requests because these are taken using TOMOYO 1.8 on CentOS 6.3.

Access request tracing function on a per-domain basis

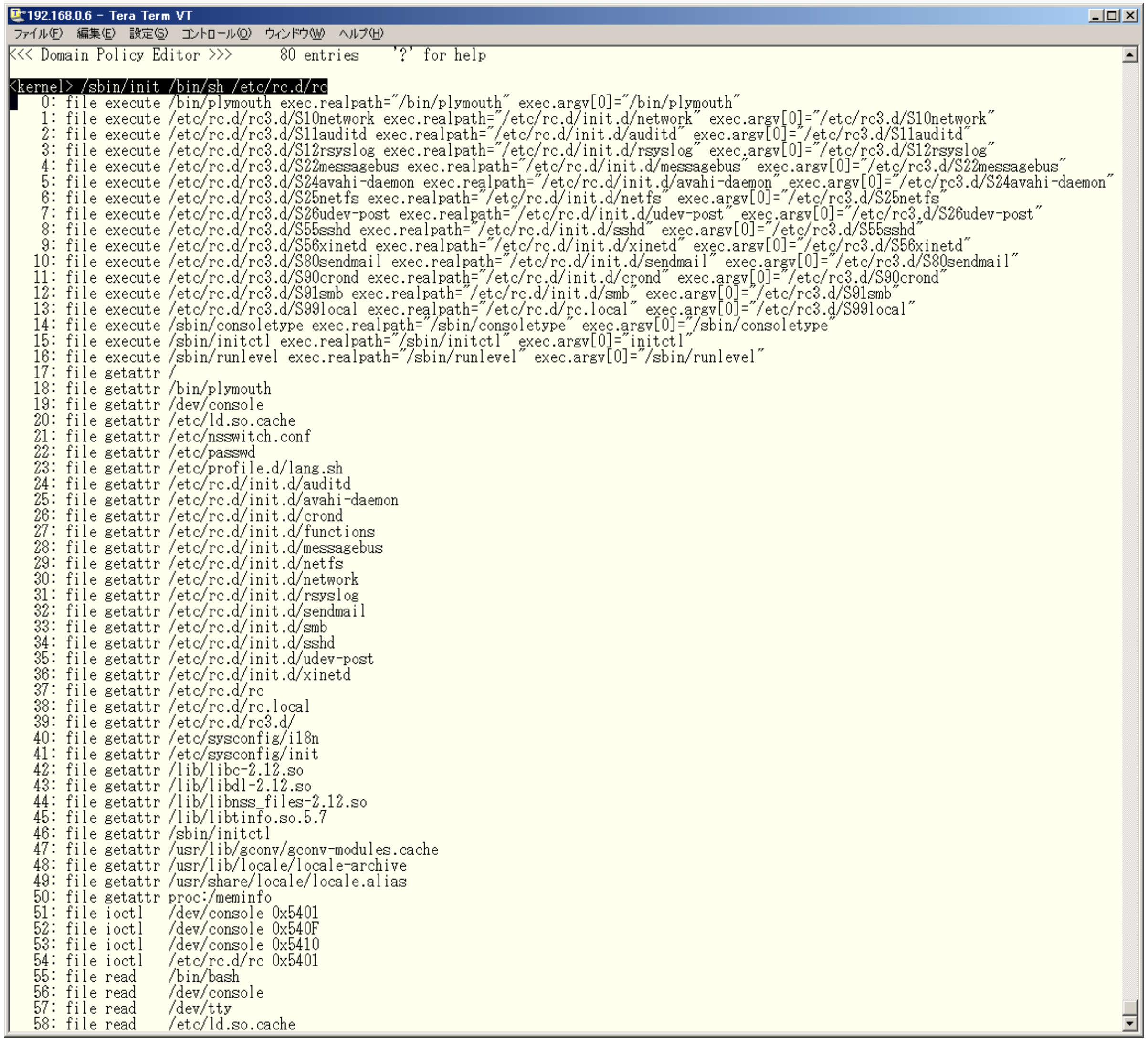


```
<<< Domain Policy Editor >>>      70 entries    '?' for help

<kernel> /sbin/init
     0: file execute /bin/kill exec.realpath="/bin/kill" exec.argv[0]="/bin/kill"
     1: file execute /bin/sh exec.realpath="/bin/bash" exec.argv[0]="/bin/sh"
     2: file execute /etc/rc.d/rc.sysinit exec.realpath="/etc/rc.d/rc.sysinit" exec.argv[0]="/etc/rc.d/rc.sysinit"
     3: file getattr /etc/group
     4: file getattr /etc/init/
     5: file getattr /etc/init/control-alt-delete.conf
     6: file getattr /etc/init/init-system-dbus.conf
     7: file getattr /etc/init/kexec-disable.conf
     8: file getattr /etc/init/plymouth-shutdown.conf
     9: file getattr /etc/init/prefdm.conf
    10: file getattr /etc/init/quit-plymouth.conf
    11: file getattr /etc/init/rc.conf
    12: file getattr /etc/init/rcS-emergency.conf
    13: file getattr /etc/init/rcS-sulogin.conf
    14: file getattr /etc/init/rcS.conf
    15: file getattr /etc/init/serial.conf
    16: file getattr /etc/init/splash-manager.conf
    17: file getattr /etc/init/start-ttys.conf
    18: file getattr /etc/init/tty.conf
    19: file getattr /etc/ld.so.cache
    20: file getattr /etc/nsswitch.conf
    21: file getattr /etc/passwd
    22: file getattr /lib/libc-2.12.so
    23: file getattr /lib/libdbus-1.so.3.4.0
    24: file getattr /lib/libgcc_s-4.4.6-20120305.so.1
    25: file getattr /lib/libnih-dbus.so.1.0.0
    26: file getattr /lib/libnih.so.1.0.0
    27: file getattr /lib/libnss_files-2.12.so
    28: file getattr /lib/libpthread-2.12.so
    29: file getattr /lib/librt-2.12.so
    30: file getattr proc:/self/fd/
    31: file ioctl   /dev/console 0x5401
    32: file ioctl   /dev/console 0x5402
    33: file ioctl   /dev/console 0x540B
    34: file ioctl   /dev/null 0x4B4E
    35: file read    /dev/console
    36: file read    /dev/null
    37: file read    /dev/urandom
    38: file read    /etc/group
    39: file read    /etc/init/
    40: file read    /etc/init/control-alt-delete.conf
    41: file read    /etc/init/init-system-dbus.conf
    42: file read    /etc/init/kexec-disable.conf
    43: file read    /etc/init/plymouth-shutdown.conf
    44: file read    /etc/init/prefdm.conf
    45: file read    /etc/init/quit-plymouth.conf
    46: file read    /etc/init/rc.conf
    47: file read    /etc/init/rcS-emergency.conf
    48: file read    /etc/init/rcS-sulogin.conf
    49: file read    /etc/init/rcS.conf
    50: file read    /etc/init/serial.conf
    51: file read    /etc/init/splash-manager.conf
    52: file read    /etc/init/start-ttys.conf
    53: file read    /etc/init/tty.conf
    54: file read    /etc/ld.so.cache
    55: file read    /etc/nsswitch.conf
    56: file read    /etc/passwd
    57: file read    /lib/ld-2.12.so
    58: file read    /lib/libc-2.12.so
    59: file read    /lib/libdbus-1.so.3.4.0
    60: file read    /lib/libgcc_s-4.4.6-20120305.so.1
    61: file read    /lib/libnih-dbus.so.1.0.0
    62: file read    /lib/libnih.so.1.0.0
    63: file read    /lib/libnss_files-2.12.so
    64: file read    /lib/libpthread-2.12.so
    65: file read    /lib/librt-2.12.so
    66: file read    /var/run/utmp
    67: file write   /dev/console
    68: file write   /dev/null
```



```
<<< Domain Policy Editor >>>      58 entries    '?' for help

<kernel> /sbin/init /bin/sh
     0: file execute  /bin/awk exec.realpath="/bin/gawk" exec.argv[0]="/bin/awk"
     1: file execute  /bin/cat exec.realpath="/bin/cat" exec.argv[0]="cat"
     2: file execute  /bin/grep exec.realpath="/bin/grep" exec.argv[0]="grep"
     3: file execute  /bin/plymouth exec.realpath="/bin/plymouth" exec.argv[0]="/bin/plymouth"
     4: file execute  /etc/rc.d/rc exec.realpath="/etc/rc.d/rc" exec.argv[0]="/etc/rc.d/rc"
     5: file execute  /sbin/initctl exec.realpath="/sbin/initctl" exec.argv[0]="initctl"
     6: file execute  /sbin/mingetty exec.realpath="/sbin/mingetty" exec.argv[0]="/sbin/mingetty"
     7: file execute  /sbin/telinit exec.realpath="/sbin/telinit" exec.argv[0]="telinit"
     8: file getattr  /
     9: file getattr  /bin/cat
    10: file getattr  /bin/grep
    11: file getattr  /etc/inittab
    12: file getattr  /etc/ld.so.cache
    13: file getattr  /etc/nsswitch.conf
    14: file getattr  /etc/passwd
    15: file getattr  /etc/sysconfig/init
    16: file getattr  /lib/libc-2.12.so
    17: file getattr  /lib/libdl-2.12.so
    18: file getattr  /lib/libnss_files-2.12.so
    19: file getattr  /lib/libtinfo.so.5.7
    20: file getattr  /sbin/initctl
    21: file getattr  /sbin/telinit
    22: file getattr  pipe:[2707]
    23: file getattr  pipe:[4815]
    24: file getattr  pipe:[4822]
    25: file getattr  pipe:[5304]
    26: file getattr  pipe:[5312]
    27: file getattr  proc:/meminfo
    28: file getattr  sysfs:/kernel/kexec_crash_size
    29: file ioctl    /dev/console 0x5401
    30: file ioctl    /dev/null 0x5401
    31: file ioctl    pipe:[2707] 0x5401
    32: file ioctl    pipe:[4815] 0x5401
    33: file ioctl    pipe:[5304] 0x5401
    34: file ioctl    pipe:[5312] 0x5401
    35: file read     /dev/
    36: file read     /dev/console
    37: file read     /dev/tty
    38: file read     /etc/ld.so.cache
    39: file read     /etc/nsswitch.conf
    40: file read     /etc/passwd
    41: file read     /etc/sysconfig/init
    42: file read     /lib/ld-2.12.so
    43: file read     /lib/libc-2.12.so
    44: file read     /lib/libdl-2.12.so
    45: file read     /lib/libnss_files-2.12.so
    46: file read     /lib/libtinfo.so.5.7
    47: file read     pipe:[2707]
    48: file read     pipe:[4815]
    49: file read     pipe:[5304]
    50: file read     pipe:[5312]
    51: file read     proc:/meminfo
    52: file truncate sysfs:/kernel/kexec_crash_size
    53: file write    /dev/console
    54: file write    /dev/null
    55: file write    /dev/tty
    56: file write    sysfs:/kernel/kexec_crash_size
```

Access request tracing function on a per-domain basis



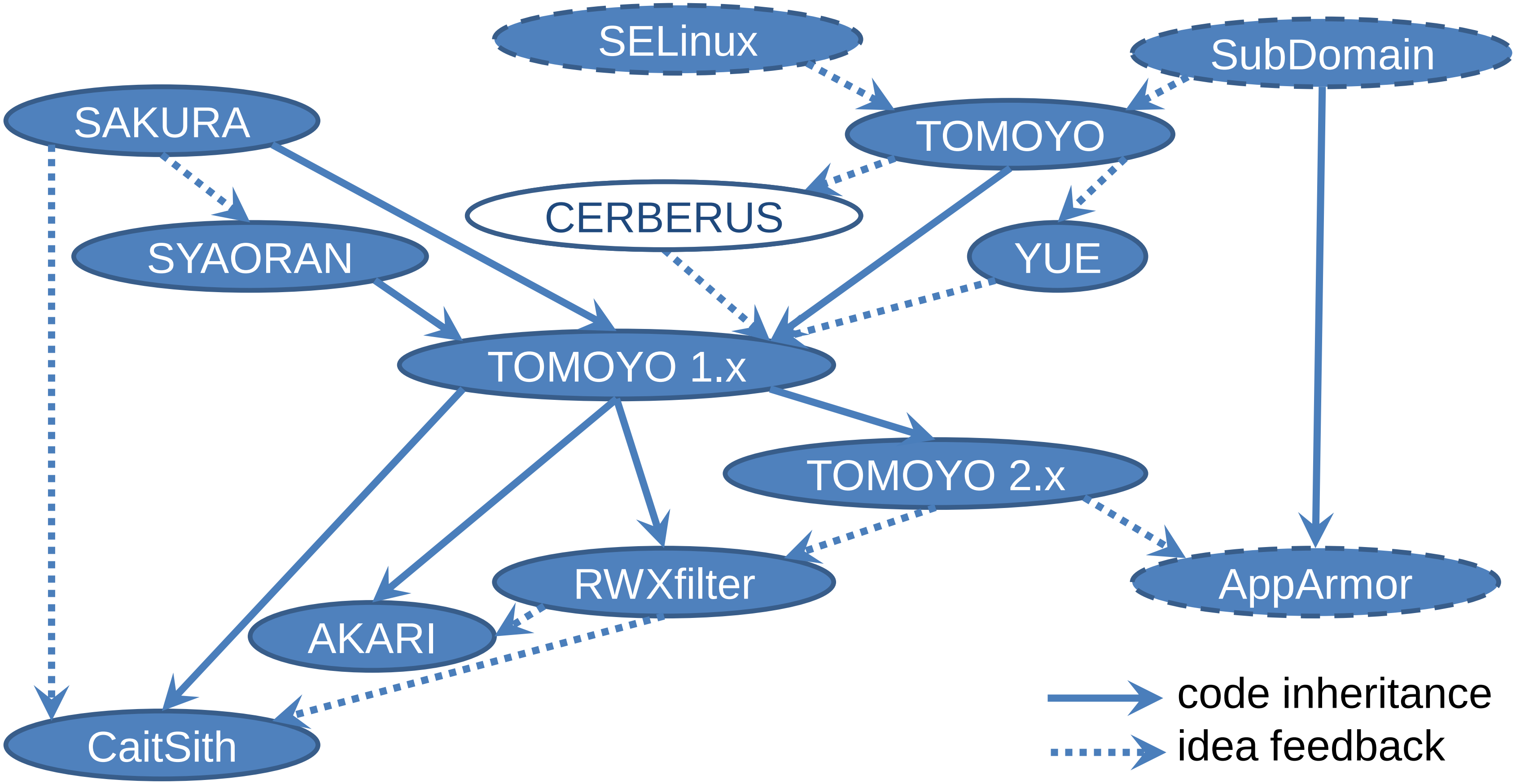
```
<<< Domain Policy Editor >>>      80 entries    '?' for help

<kernel> /sbin/init /bin/sh /etc/rc.d/rc
    0: file execute /bin/plymouth exec.realpath="/bin/plymouth" exec.argv[0]="/bin/plymouth"
    1: file execute /etc/rc.d/rc3.d/S10network exec.realpath="/etc/rc.d/init.d/network" exec.argv[0]="/etc/rc3.d/S10network"
    2: file execute /etc/rc.d/rc3.d/S11auditd exec.realpath="/etc/rc.d/init.d/auditd" exec.argv[0]="/etc/rc3.d/S11auditd"
    3: file execute /etc/rc.d/rc3.d/S12rsyslog exec.realpath="/etc/rc.d/init.d/rsyslog" exec.argv[0]="/etc/rc3.d/S12rsyslog"
    4: file execute /etc/rc.d/rc3.d/S22messagebus exec.realpath="/etc/rc.d/init.d/messagebus" exec.argv[0]="/etc/rc3.d/S22messagebus"
    5: file execute /etc/rc.d/rc3.d/S24avahi-daemon exec.realpath="/etc/rc.d/init.d/avahi-daemon" exec.argv[0]="/etc/rc3.d/S24avahi-daemon"
    6: file execute /etc/rc.d/rc3.d/S25netfs exec.realpath="/etc/rc.d/init.d/netfs" exec.argv[0]="/etc/rc3.d/S25netfs"
    7: file execute /etc/rc.d/rc3.d/S26udev-post exec.realpath="/etc/rc.d/init.d/udev-post" exec.argv[0]="/etc/rc3.d/S26udev-post"
    8: file execute /etc/rc.d/rc3.d/S55sshd exec.realpath="/etc/rc.d/init.d/sshd" exec.argv[0]="/etc/rc3.d/S55sshd"
    9: file execute /etc/rc.d/rc3.d/S56xinetd exec.realpath="/etc/rc.d/init.d/xinetd" exec.argv[0]="/etc/rc3.d/S56xinetd"
   10: file execute /etc/rc.d/rc3.d/S80sendmail exec.realpath="/etc/rc.d/init.d/sendmail" exec.argv[0]="/etc/rc3.d/S80sendmail"
   11: file execute /etc/rc.d/rc3.d/S90crond exec.realpath="/etc/rc.d/init.d/crond" exec.argv[0]="/etc/rc3.d/S90crond"
   12: file execute /etc/rc.d/rc3.d/S91smb exec.realpath="/etc/rc.d/init.d/smb" exec.argv[0]="/etc/rc3.d/S91smb"
   13: file execute /etc/rc.d/rc3.d/S99local exec.realpath="/etc/rc.d/rc.local" exec.argv[0]="/etc/rc3.d/S99local"
   14: file execute /sbin/consoletype exec.realpath="/sbin/consoletype" exec.argv[0]="/sbin/consoletype"
   15: file execute /sbin/initctl exec.realpath="/sbin/initctl" exec.argv[0]="initctl"
   16: file execute /sbin/runlevel exec.realpath="/sbin/runlevel" exec.argv[0]="/sbin/runlevel"
   17: file getattr /
   18: file getattr /bin/plymouth
   19: file getattr /dev/console
   20: file getattr /etc/ld.so.cache
   21: file getattr /etc/nsswitch.conf
   22: file getattr /etc/passwd
   23: file getattr /etc/profile.d/lang.sh
   24: file getattr /etc/rc.d/init.d/auditd
   25: file getattr /etc/rc.d/init.d/avahi-daemon
   26: file getattr /etc/rc.d/init.d/crond
   27: file getattr /etc/rc.d/init.d/functions
   28: file getattr /etc/rc.d/init.d/messagebus
   29: file getattr /etc/rc.d/init.d/netfs
   30: file getattr /etc/rc.d/init.d/network
   31: file getattr /etc/rc.d/init.d/rsyslog
   32: file getattr /etc/rc.d/init.d/sendmail
   33: file getattr /etc/rc.d/init.d/smb
   34: file getattr /etc/rc.d/init.d/sshd
   35: file getattr /etc/rc.d/init.d/udev-post
   36: file getattr /etc/rc.d/init.d/xinetd
   37: file getattr /etc/rc.d/rc
   38: file getattr /etc/rc.d/rc.local
   39: file getattr /etc/rc.d/rc3.d/
   40: file getattr /etc/sysconfig/i18n
   41: file getattr /etc/sysconfig/init
   42: file getattr /lib/libc-2.12.so
   43: file getattr /lib/libdl-2.12.so
   44: file getattr /lib/libnss_files-2.12.so
   45: file getattr /lib/libtinfo.so.5.7
   46: file getattr /sbin/initctl
   47: file getattr /usr/lib/gconv/gconv-modules.cache
   48: file getattr /usr/lib/locale/locale-archive
   49: file getattr /usr/share/locale/locale.alias
   50: file getattr proc:/meminfo
   51: file ioctl   /dev/console 0x5401
   52: file ioctl   /dev/console 0x540F
   53: file ioctl   /dev/console 0x5410
   54: file ioctl   /etc/rc.d/rc 0x5401
   55: file read    /bin/bash
   56: file read    /dev/console
   57: file read    /dev/tty
   58: file read    /etc/ld.so.cache
```

Access request restricting function on a per-domain basis

- I attempted to generate SELinux's policy from the output.
  - I gave up because I could not map TOMOYO's pathnames into SELinux's labels.
- Instead, I added function to restrict access requests based on the observed output
  - At this time, I didn't distinguish requests for modifying directory entries.
    - In other words, the granularity was similar to DAC's rwx.

CERBERUS (2004.1-)

- One of advanced usages of TOMOYO, which protects from login brute force attacks.

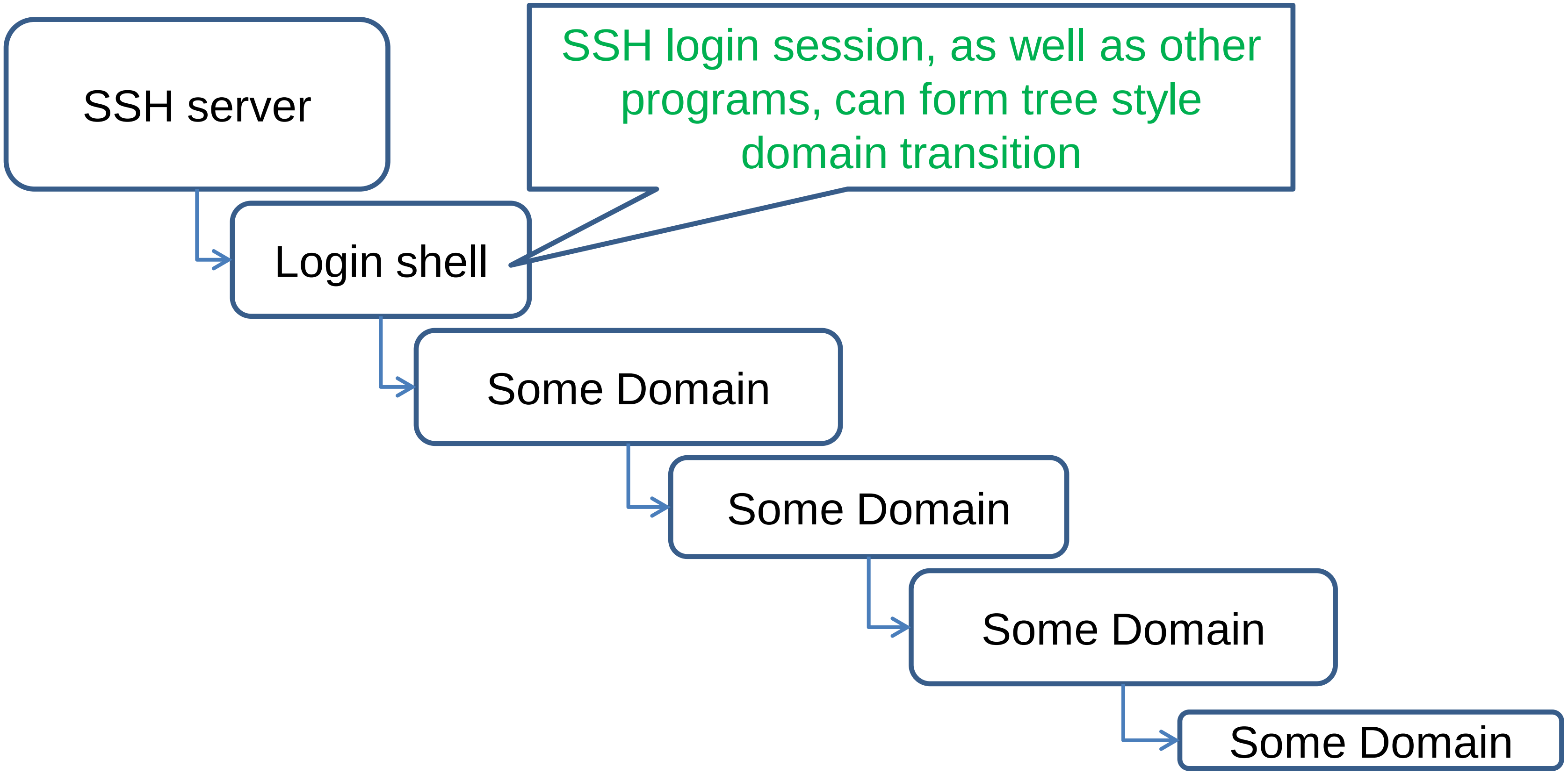


CERBERUS

- SSH brute force attacks can break protection by MAC.
  - Why not to enforce extra authentications?
- Code name: "Chained Enforceable Re-authentication Barrier Ensures Really Unbreakable Security"
- Topics on CERBERUS
  - Anti brute force technique via multiplexed user authentication.

Anti brute force technique via multiplexed user authentication.

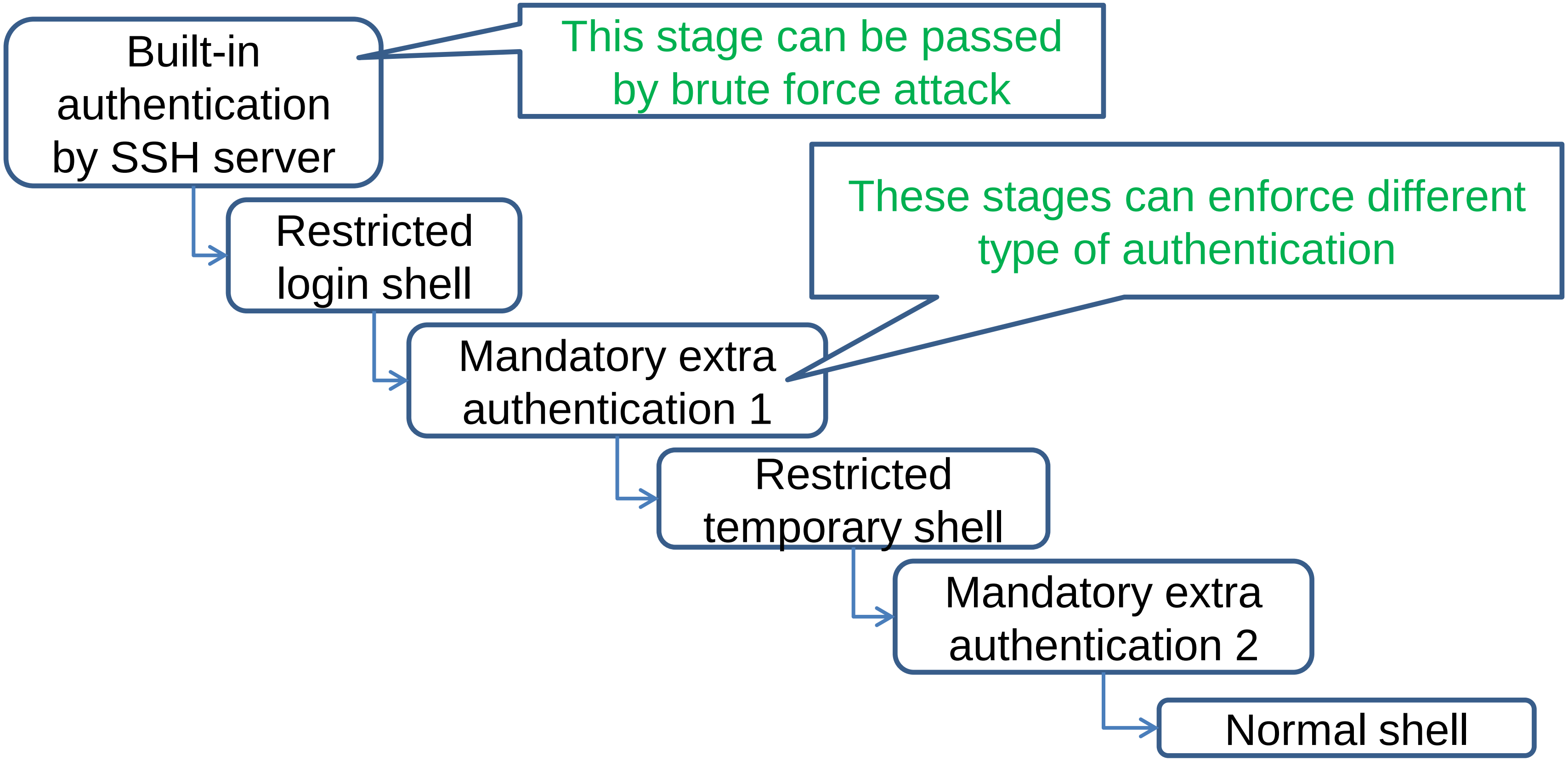
- I noticed that we can deploy user authentications for multiple times, by using TOMOYO's tree style state transition.



SSH login session, as well as other programs, can form tree style domain transition

Anti brute force technique via multiplexed user authentication.

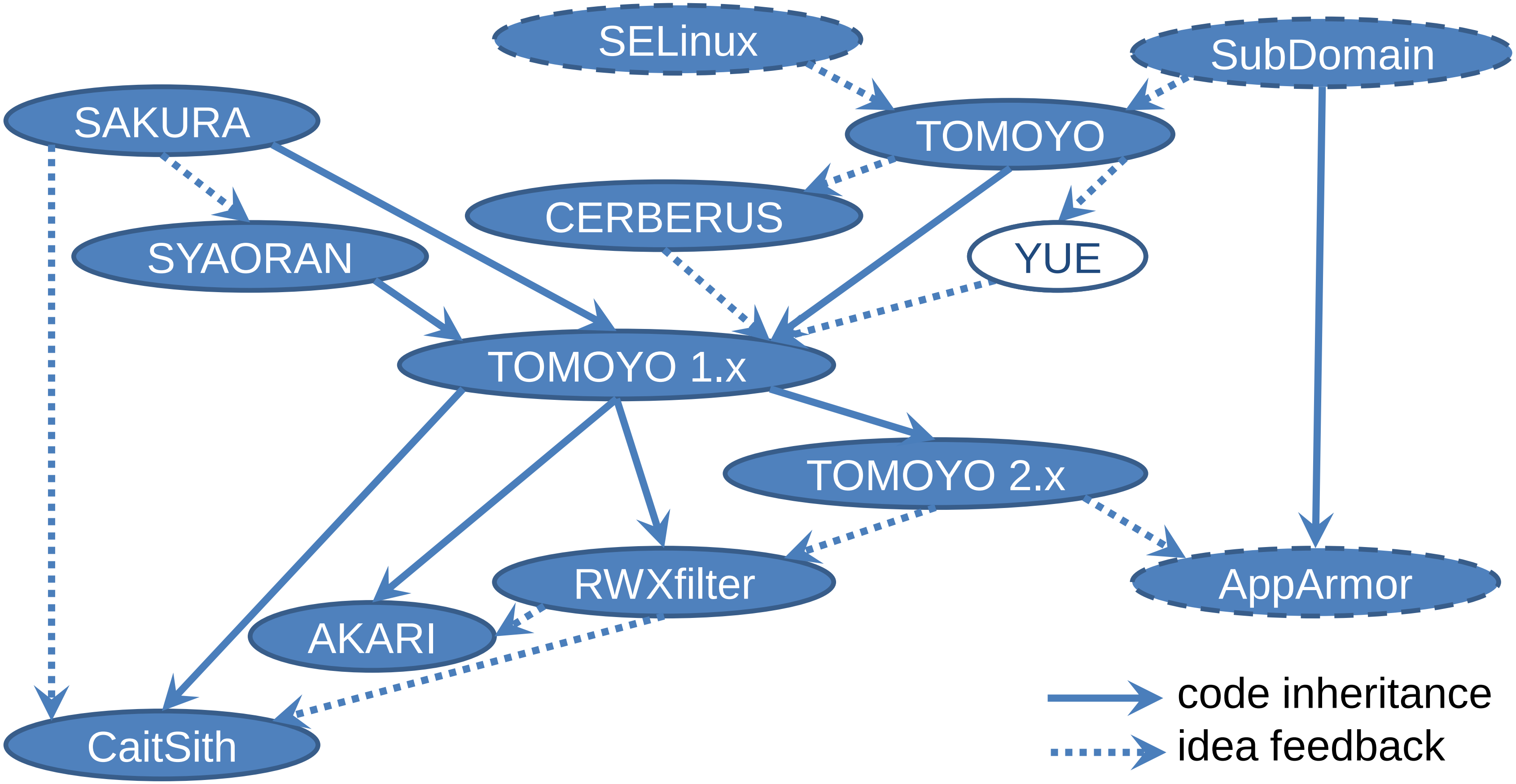
- I noticed that we can deploy user authentications for multiple times, by using TOMOYO's tree style state transition.



Built-in authentication by SSH server
This stage can be passed by brute force attack
Restricted login shell
These stages can enforce different type of authentication
Mandatory extra authentication 1
Restricted temporary shell
Mandatory extra authentication 2
Normal shell

YUE (2004.1-)

- One of advanced usages of TOMOYO, which divides privileges for administrative jobs.

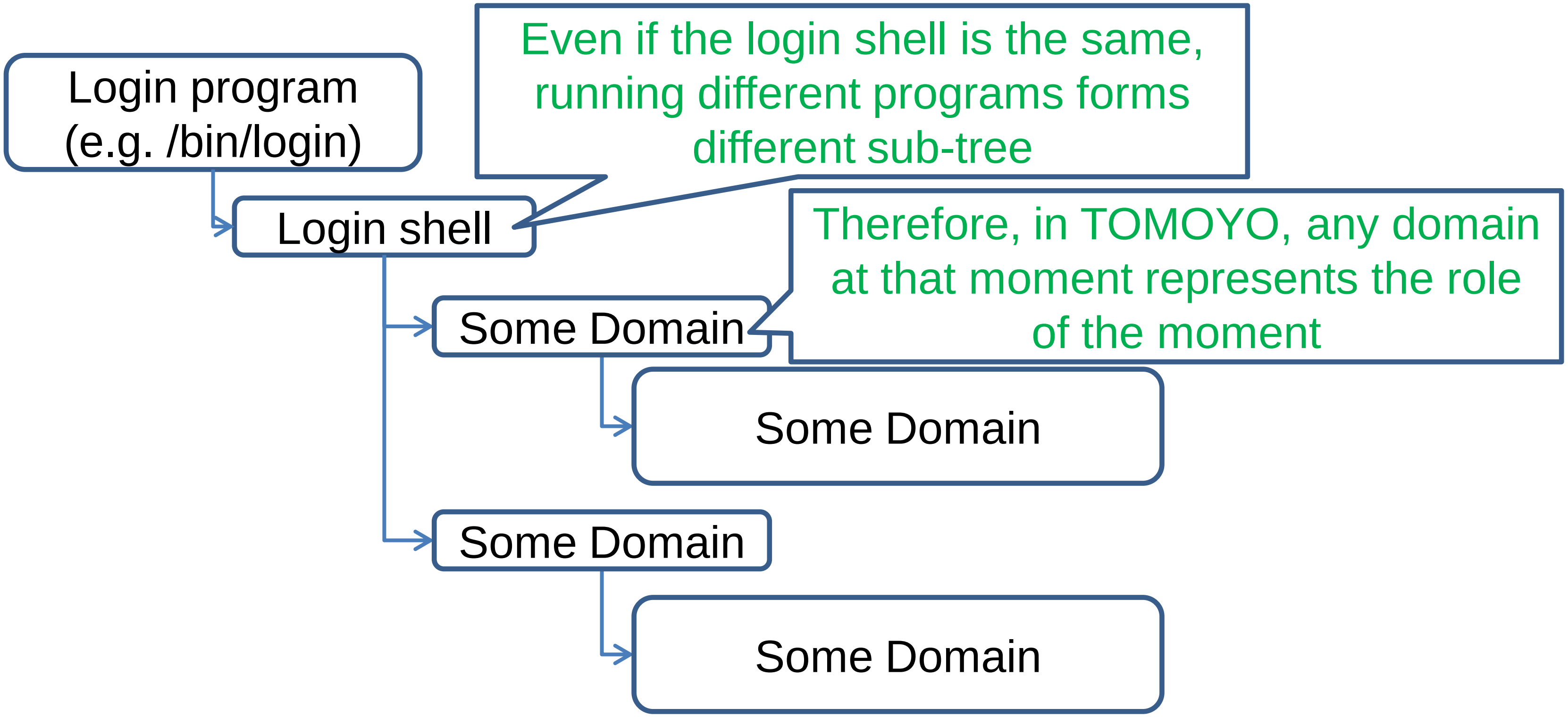


YUE

- The root privileges are needed for doing administrative jobs.
  - But only one root user can exist.
    - Why not to divide privileges using TOMOYO's tree style state transition?
- Code name: "Your User-role Enforcer"
- Topics on YUE
  - Privilege division technique like Role Based Access Control (RBAC)

Privilege division technique like Role Based Access Control (RBAC)

- I noticed that we can divide privileges for administrative jobs into arbitrary groups, by using TOMOYO's tree style state transition.

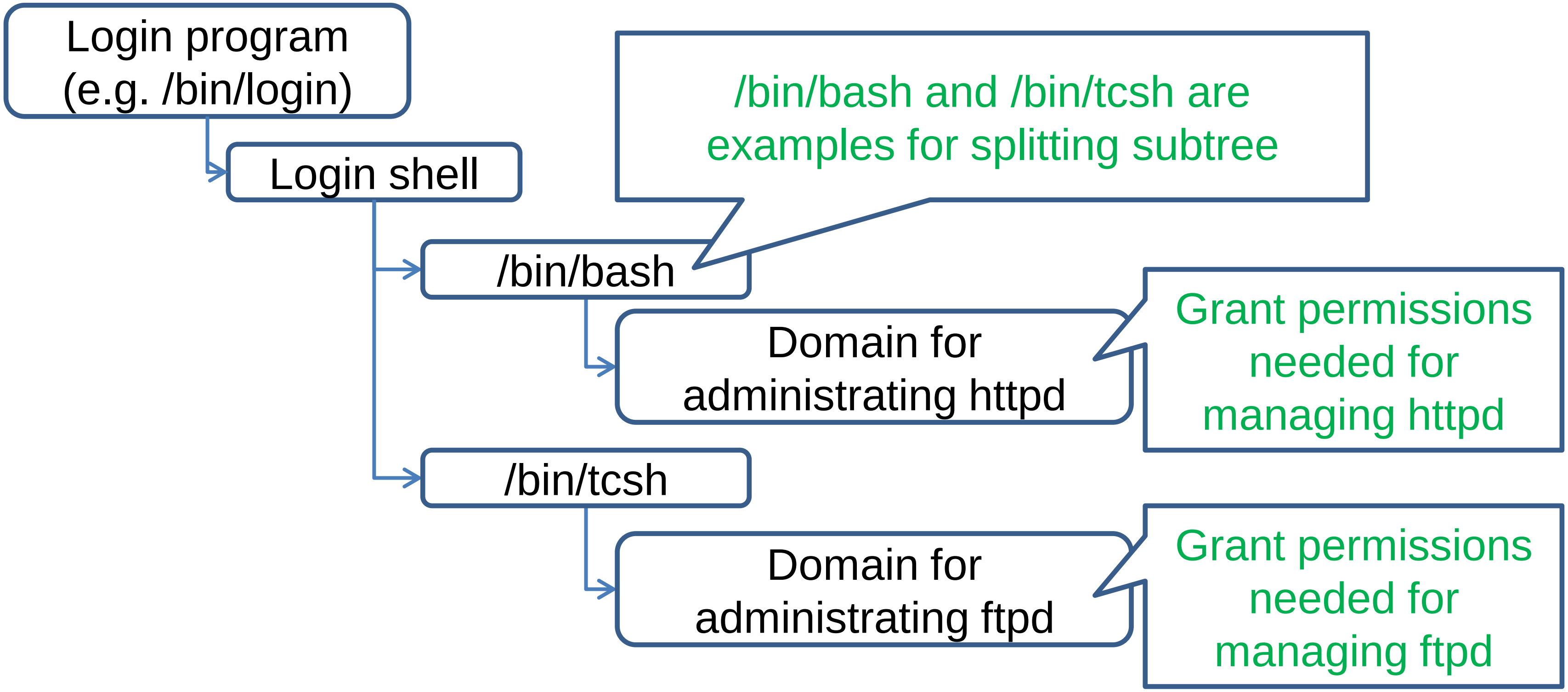


Even if the login shell is the same, running different programs forms different sub-tree

Therefore, in TOMOYO, any domain at that moment represents the role of the moment

Privilege division technique like Role Based Access Control (RBAC)

- I noticed that we can divide privileges for administrative jobs into arbitrary groups, by using TOMOYO's tree style state transition.


Login program
(e.g. /bin/login)
Login shell
/bin/bash
Domain for administrating httpd
/bin/tcsh
Domain for administrating ftpd

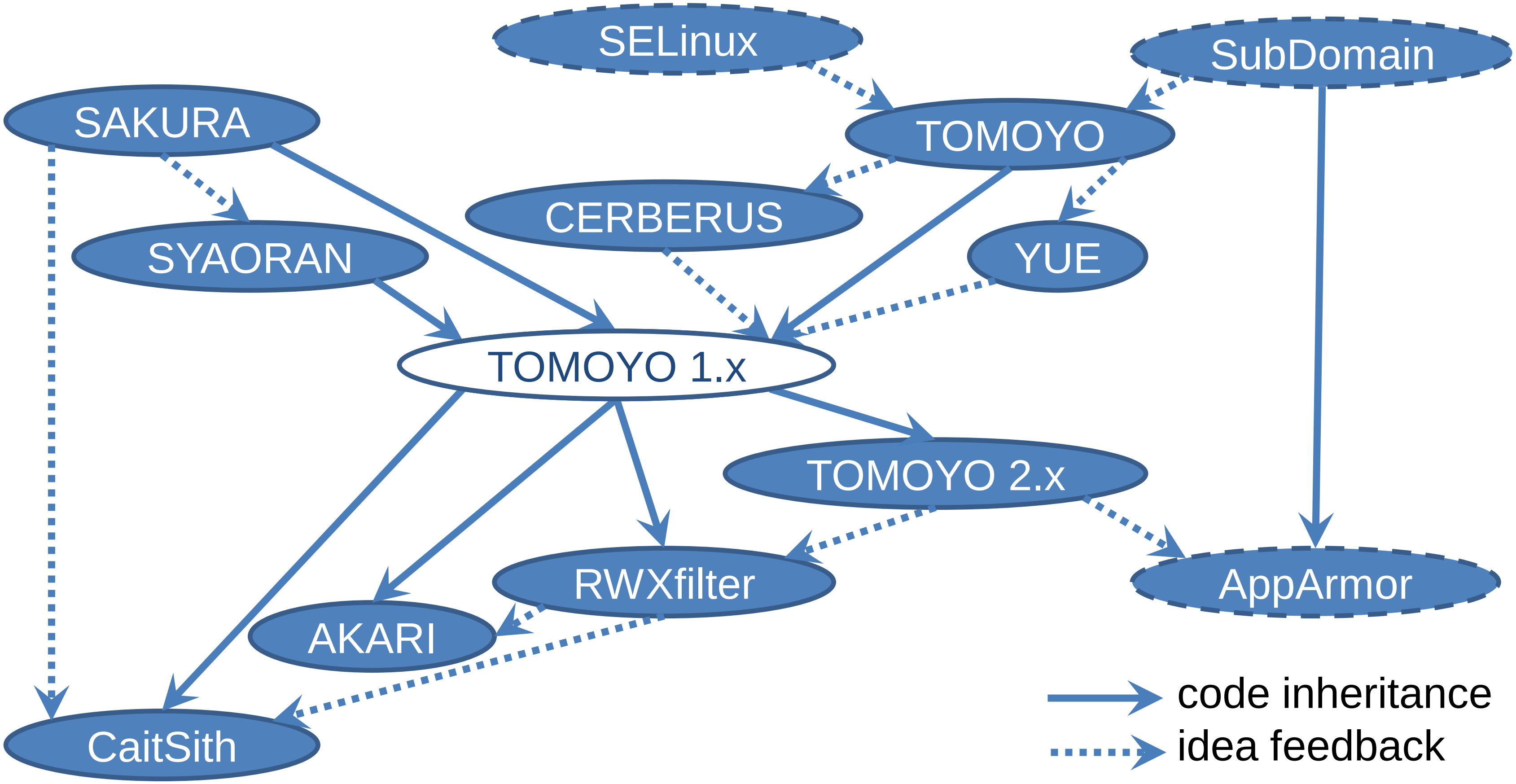
/bin/bash and /bin/tcsh are examples for splitting subtree

Grant permissions needed for managing httpd

Grant permissions needed for managing ftpd

TOMOYO 1.x (2005.11-)

- The origin of my various derivative works.



TOMOYO 1.0 (2005.11-2006.3)

- A version which was published as a GPL open source software with outcomes since 2003.4.
  - SAKURA which handles restriction of namespace manipulation on system-wide basis
  - TOMOYO which handles restriction of access requests on a per-domain basis
  - SYAORAN which protects /dev partition
  - CERBERUS which protects from login brute force attacks
  - YUE which divides privileges for administrative jobs

TOMOYO 1.1 (2006.4-2006.9)

- User space programs behaves differently depending on names.
  - Gear towards more strictly restricting names which affects program's behavior, in addition to restricting whether the pathname is readable/writable/executable or not.
    - Differentiate directory entry modification actions (i.e. mkdir, rmdir, create, unlink, mksock, mkfifo, mkchar, mkblock, link, symlink, rename, truncate) from "write" action.
- Made it possible to handle policy violations interactively.
  - Give users a chance to handle unexpected events which sometimes occur upon running software updater(e.g. yum/apt).

TOMOYO 1.2 (2006.9-2006.11)

- Check invocation name (a.k.a. argv[0]) upon checking program's execute permission.
  - Because multi-call programs (e.g. busybox) behave differently depending on the invocation name.
- Check current process's user ID etc. and file's owner ID etc. upon checking permissions.
  - Checking only pathname is not sufficient.

TOMOYO 1.3 (2006.11-2006.3)

- Made it possible to specify whether to enforce access control or not, on a per-domain basis by introducing profile number which takes an integer between 0 and 255.
  - Profile number allowed users to use TOMOYO like SELinux's targeted policy.
  - Profile number also allowed users to use different functionality on different programs.
- Made it possible to suppress/reset domain transitions as needed.
  - Support various patterns of domain transition.

TOMOYO 1.4 (2007.4-2007.9)

- Support pathname subtraction operator.
  - Generally, filenames starting with a dot should be treated differently.
  - /var/www/html/*\-.*
    - For example, differentiate /var/www/html/.htaccess from /var/www/html/index.html
- Support x86_64 architecture.
- Started developing an LSM version called TOMOYO 2.x and started challenges for inclusion into Linux mainline kernel.
  - TOMOYO Linux project had a BoF session at Ottawa Linux Symposium 2007.

TOMOYO 1.5 (2007.9-2008.3)

- Improved usability in order to differentiate TOMOYO from AppArmor.
  - At that time, TOMOYO was challenging for inclusion into Linux mainline kernel. But since both TOMOYO and AppArmor used pathnames in their policy configuration, TOMOYO and AppArmor are regarded as "no need to include both implementations into Linux mainline".
  - I tried to show how attentive TOMOYO is.
- Made possible to run TOMOYO 1.x in parallel with SELinux.
  - The label based MAC and the name based MAC play complementary role.
    - Thus, these should be able to run in parallel.

TOMOYO 1.6 (2008.4-)

- Various functionality/usability enhancements
  - check argv[]/envp[] upon program execution
  - support execute handler which intercepts program execution request and validates/sanitizes argv[]/envp[] etc.
    - This can silently terminate a process if the process issued suspicious execve() request (e.g. /bin/sh without appropriate argv[]/envp[])
  - support stateful acl
  - and many more
- This is the base code for RWXfilter and TOMOYO 2.2.

TOMOYO 1.7 (2009.9-)

- Current stable version.
- Checks not only pathnames but also various attributes passed together.
- Changed module name of TOMOYO 1.x to CCSecurity since TOMOYO 2.2 was included into Linux mainline kernel.
  - Took occasion to review the division of the roles.
    - Integrate system-wide access restrictions (SAKURA) into a per-domain access restrictions (TOMOYO).
    - Integrate access restrictions in /dev filesystem (SYAORAN) into a per-domain access restrictions (TOMOYO).

System-wide access restriction vs. A per-domain access restriction

- Why did I treat system-wide access restriction and a per-domain access restriction separately?
  - Mainly enthusiasm for the code names.
- In order to restrict more precisely, why not to specify on a per-domain basis rather than system-wide basis, for TOMOYO 1.x can apply access restrictions to all processes?
  - I thought (at that time) "Definitely".
- As a background of this decision, I was targeting for more finer grained restriction in order to support LXC (pivot_root) users.
  - Since TOMOYO 2.2 supported only TOMOYO (a per-domain access restriction), I removed SAKURA (system-wide access restriction) from TOMOYO 1.7.

Access restriction by filesystems vs. Access restriction by domains

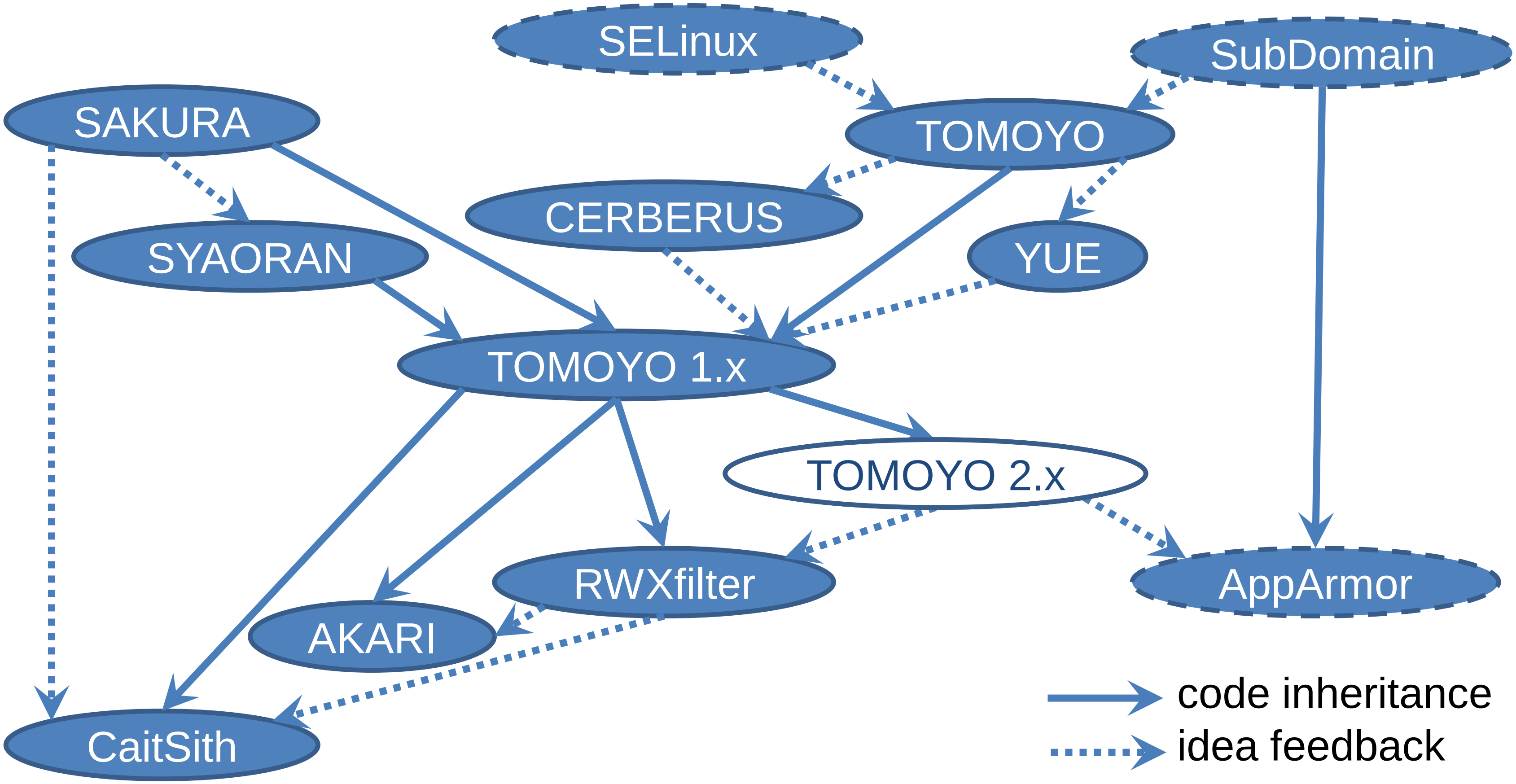
- Why did I have to restrict at filesystem layer? Now, TOMOYO can check not only filenames but also file's attributes. Should I continue maintaining /dev filesystem?
  - I thought (at that time) "Not worth maintaining".
    - I removed SYAORAN filesystem from TOMOYO 1.7, for SYAORAN filesystem conflicts with udev approach.

TOMOYO 1.8 (2010.11-)

- Current latest version which supports Linux 2.6.27-3.5 kernels.
- Reviewed internal structures, removed redundant/legacy functionality, renamed keywords in the policy syntax.
- Made it possible to preserve kernel ABI by introducing hooks into fork() and exit() (instead of appending original fields to task_struct which results in kernel ABI breakage).
  - It became possible to treat like distributor's stock kernels.
- This is the base code for AKARI and CaitSith.

TOMOYO 2.x (2007.6-)

- The mainlined version of TOMOYO 1.x.



TOMOYO 2.2 (2009.6-2010.10)

- A version which was mainlined in Linux 2.6.30 kernel.
- Only core function of TOMOYO 1.6 is implemented.
- Addition of missing LSM hooks for file related actions has completed by Linux 2.6.33 kernel.

TOMOYO 2.3 (2010.10-2011.10)

- A version which was included into Linux 2.6.36-3.0 kernels.
- Major functionality regarding file related actions in TOMOYO 1.7 is implemented.

TOMOYO 2.4 (2011.10-2012.1)

- A version which was included into Linux 3.1 kernel.
- A version which has practically usable function.
- Major functionality regarding file related actions in TOMOYO 1.8 is implemented.

TOMOYO 2.5 (2012.1-)

- A version which is included into Linux 3.2 and later kernels.
  - It is possible to backport this version up to Linux 2.6.33 kernel without modifying outside of security/tomoyo/ directory.
- Major functionality in TOMOYO 1.8 is implemented.
- Not yet implemented functionality
  - execute handler
  - Checking permission of incoming network packets.
  - capability (Maybe seccomp mode 2 can substitute?)
  - Checking permission of binary loader programs.
  - Running with other LSM modules in parallel.

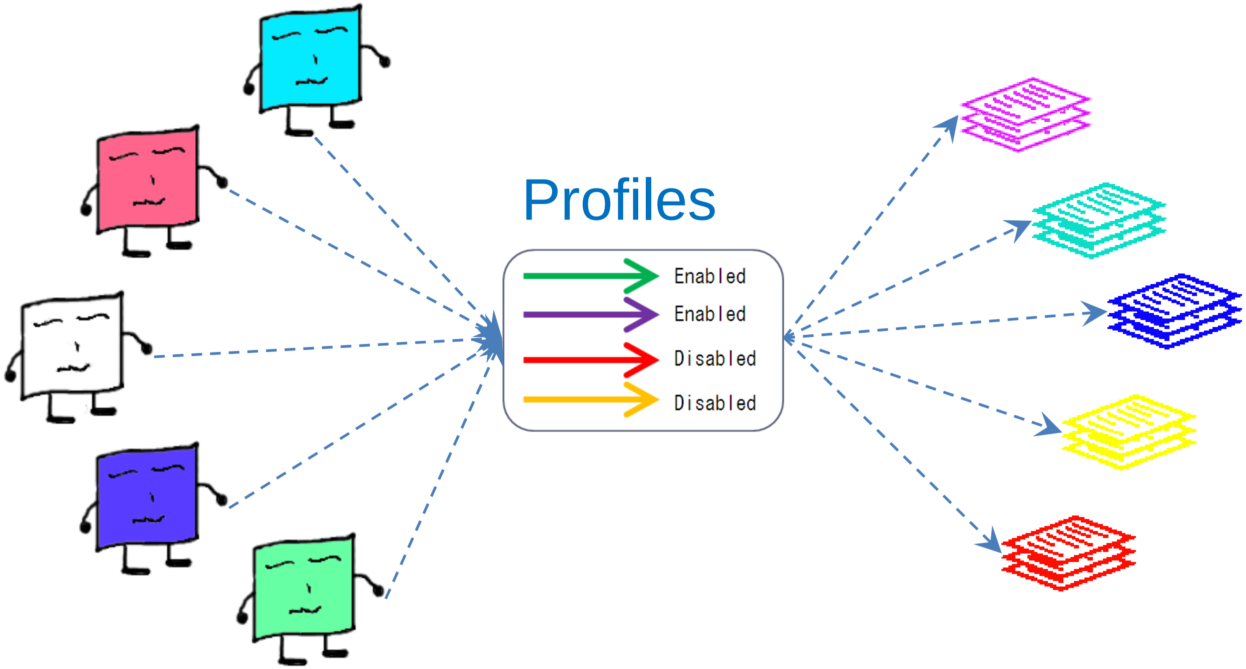
Things I achieved

- In-kernel access control which takes into account side effects in the user space
  - Preserving only "whether the file is readable/writable/executable or not" is not sufficient.
  - Firewall which checks various parameters which are represented in the form of string or numeric values.
- Know all possible behaviors from boot to shutdown.
  - Covers all processes
    - Use task_struct for defining domains.
  - Sense of safety that can cover all processes
    - TOMOYO 1.8 is used in Android devices.
  - Focuses on preventing from unwanted behaviors.

Things I struggled

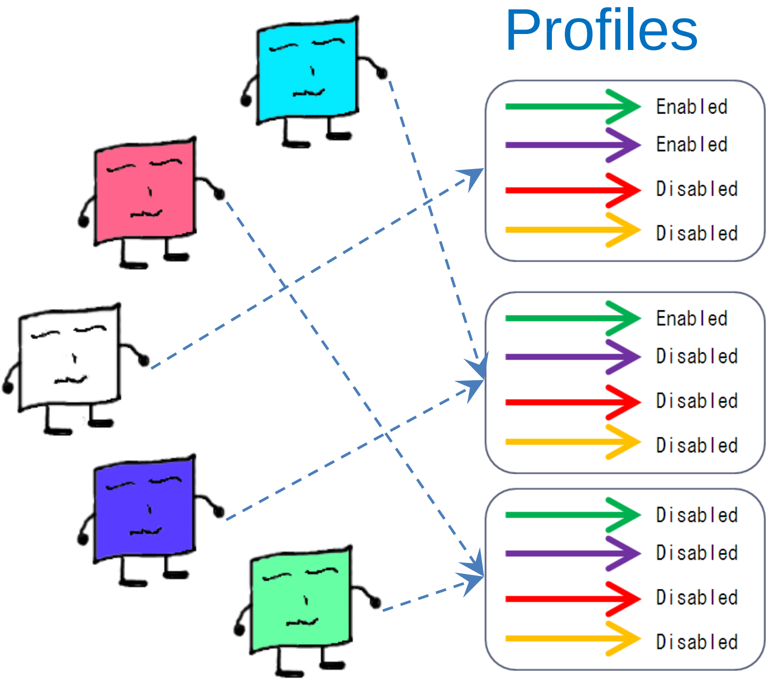
- Implement functionality which will be useful, while keeping psychological barrier as low as possible.

- First step(2005.11)
  - I made it possible to enable/disable on a per-action basis.



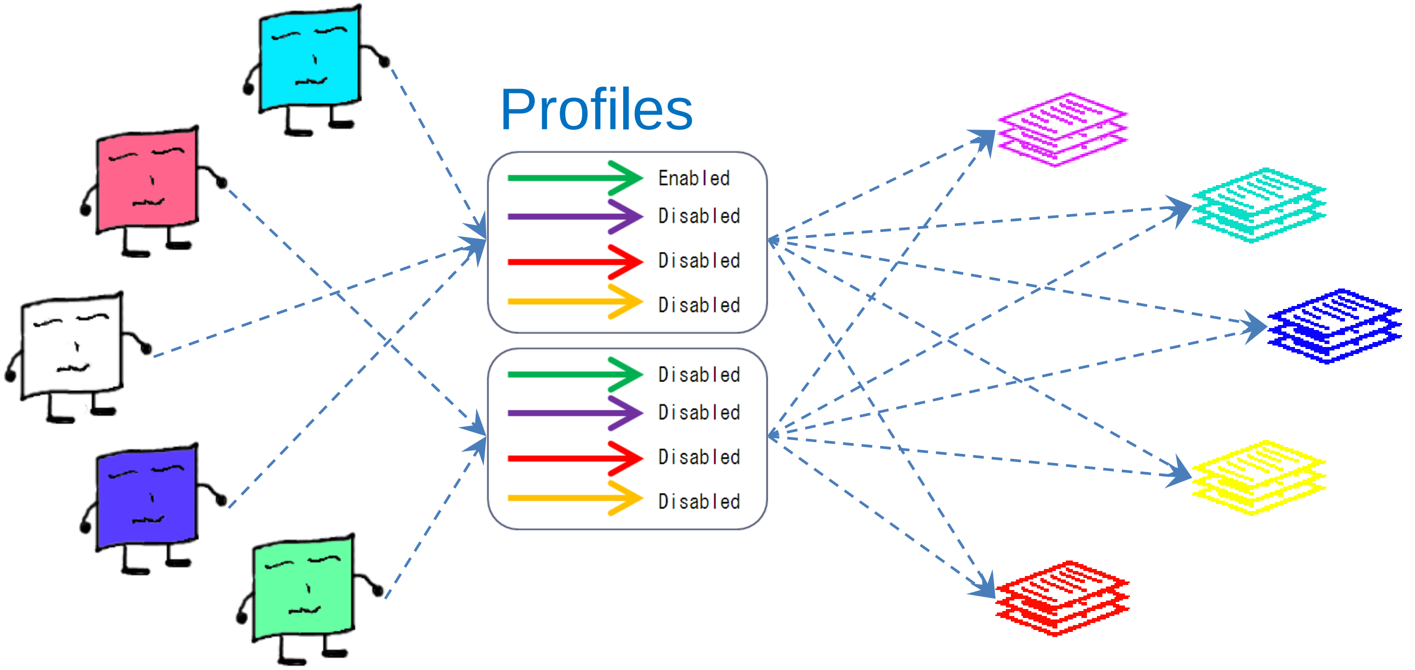
Things I struggled

- Second step(2006.11)
  - Even though TOMOYO can apply restrictions on all processes, user's skill are not catching up.
  - I made it possible to enable/disable access restrictions on a per-domain basis.
    - This also made it possible to use build-up approach by switching profiles after the policy is developed.



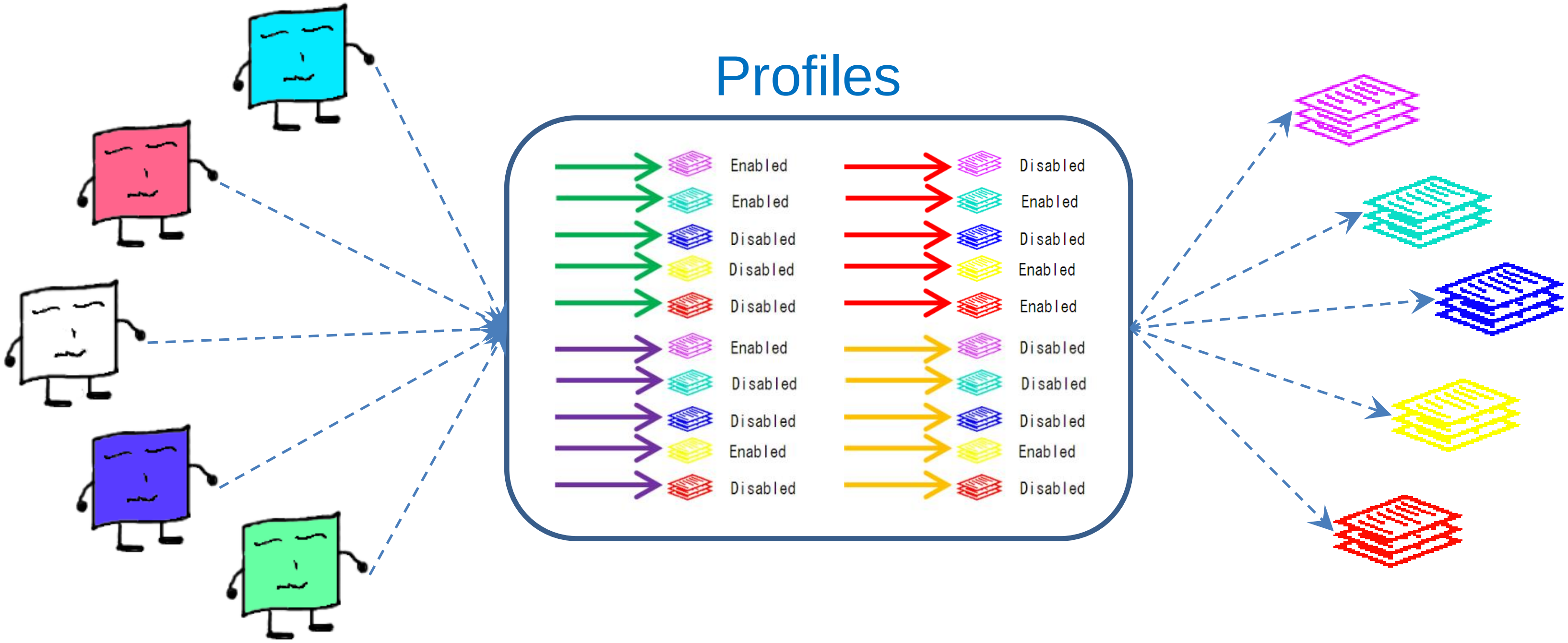
Things I struggled

- Third step(2011)
  - Even if restricting only file related actions, it is too difficult to switch all files to enforcing mode at once.



Things I struggled

- Third step(2011)
  - I considered profiles on a per-filename basis.
    - I didn't implement because it will become too messy.



Profiles

Enabled
Enabled
Disabled
Disabled
Disabled

Enabled
Disabled
Disabled
Enabled
Disabled

Disabled
Enabled
Disabled
Enabled
Enabled

Disabled
Disabled
Disabled
Enabled
Disabled

Things I struggled

- Third step(2011)
  - I considered blacklisting approach.
    - I didn't implement because it conflicts access control modes in the profiles
      - The permissive mode is defined as "check access requests but do not reject", but blacklisting will make the permissive mode no longer permissive.
    - It is impossible to apply blacklisting approach before defining domains.
      - How should TOMOYO handle blacklist when TOMOYO automatically generated domains?

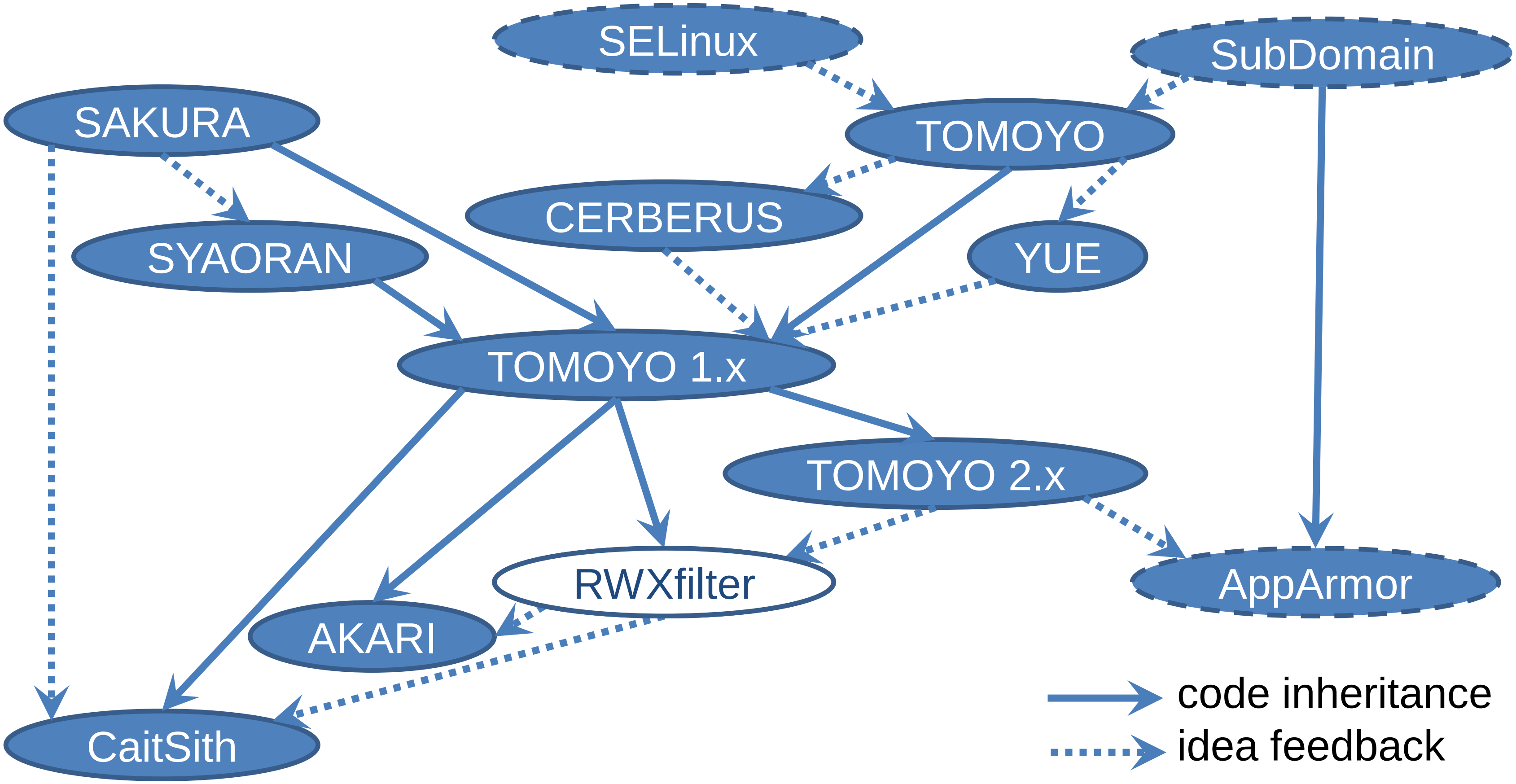
=> Leads to CaitSith

Chapter 3

Things I experienced with continuing enhancement of ease of use

RWXfilter (2010.2-2010.4)

- The trigger for seriously considering Linux user's real opinions.



A request from RHEL users.

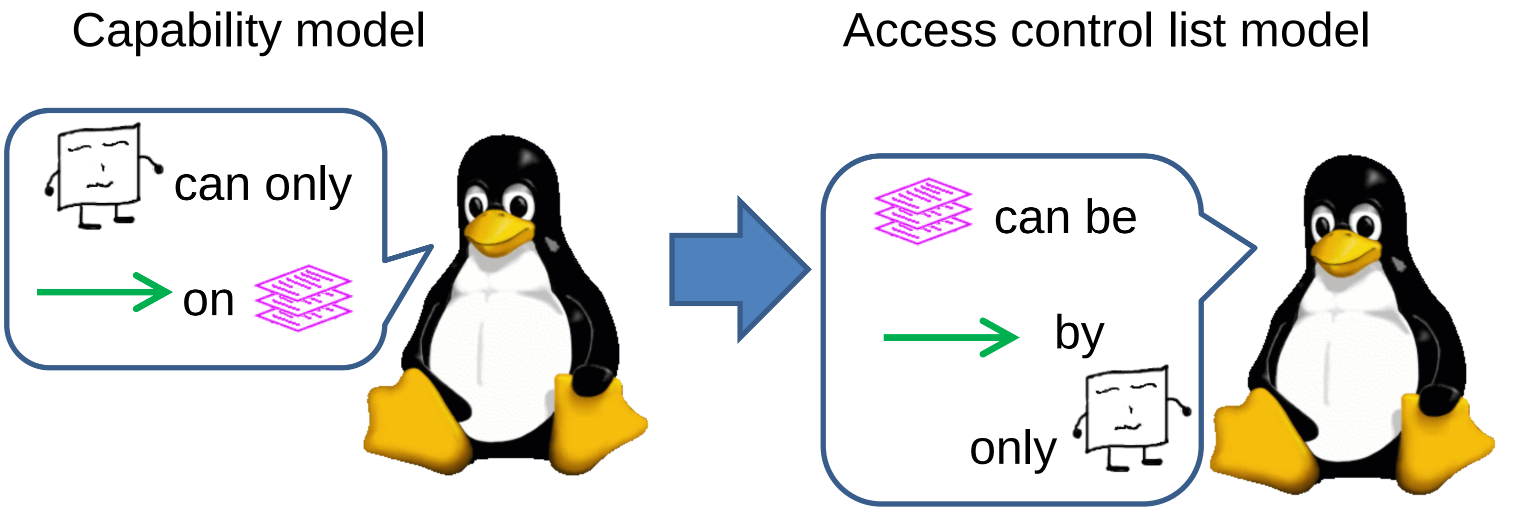
- SELinux is too difficult for us to use. Please develop a single function access control mechanism that can be loaded into RHEL kernels as a loadable kernel module.
  - I decided to implement a loadable kernel module that makes use of LSM interface.
- Please allow users to apply access control on only specific files.
  - I decided to filter only "read/write/execute" actions in order to minimize barrier for users.
    - Code name: "Read/Write/Execute filter", or in short "RWXfilter".

Dilemmas

- Existing MAC implementations assume "define domains first, and then associate permissions/resources to domains".
  - But it is difficult to apply such approach to all processes.
- But it ruins the value of MAC if there is a process which such approach is not applied.
  - But we cannot impose on users the burden of managing every process only for applying access control on some specific resources.

I reversed the viewpoints.

- Switch from "define domains first, and then associate actions/resources" to "define resources first, and then associate actions/domains".



Capability model

can only

on

Access control list model

can be

by

only

Policy syntax for RWXfilter

- "Resource" "Access Control Mode"
  "Action1" by "Domain1 which action1 is allowed"
  "Action2" by "Domain2 which action2 is allowed"
  "Action3" by "Domain3 which action3 is allowed"
  - "Resource" is TOMOYO's pathname representation.
  - "Access Control Mode" is either "permissive" or "enforcing".
  - "ActionX" is one of "read", "write" or "execute".
  - "DomainX which actionX is allowed" is TOMOYO's domainname representation.

An example of RWXfilter's policy

- /etc/shadow enforcing

  read by <kernel> /sbin/init /sbin/mingetty /bin/login

  read by <kernel> /usr/sbin/sshd

  - This example will allow opening /etc/shadow for reading to only processes which are in "<kernel> /sbin/init /sbin/mingetty /bin/login" domain or "<kernel> /usr/sbin/sshd" domain.
  - This example will deny opening /etc/shadow for writing, for access control mode for this pathname is "enforcing".

Consequence

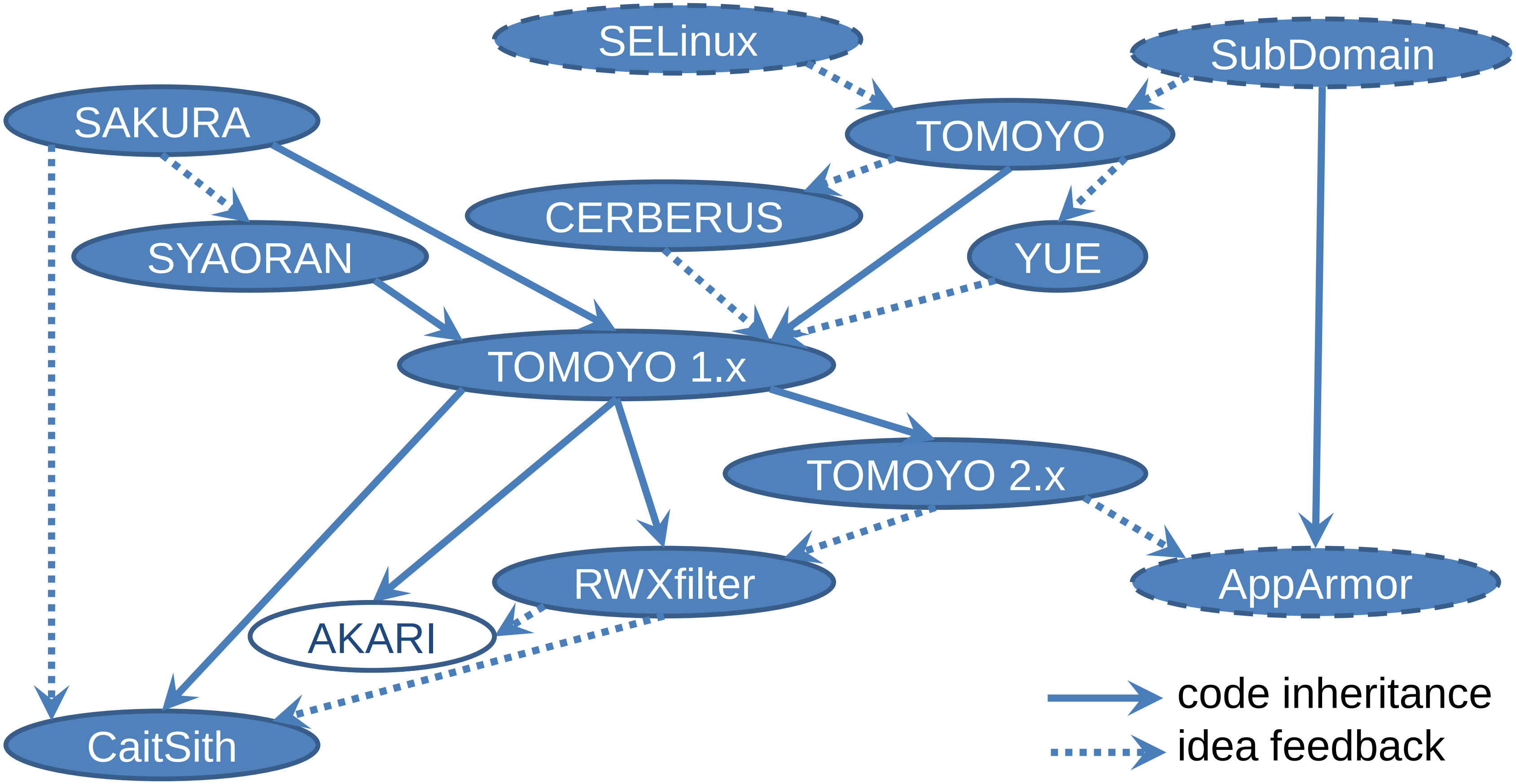
- RWXfilter was shelved because I could not establish commercial support.
  - But RWXfilter triggered me to explorer the possibility of access controls from different point of view.

  => Leads to CaitSith.
- I established an approach for appending another LSM module as a loadable kernel module without disabling SELinux.
  - I demonstrated Yama with TOMOYO 2.x at Linux Security Summit held in conjunction with LinuxCon North America 2010 (Boston).

  => Leads to AKARI.

AKARI (2010.10-)

- The loadable kernel module version of TOMOYO 1.8.



Origination

- TOMOYO 2.x remains unsupported in Fedora and RHEL kernels.
  - https://bugzilla.redhat.com/show_bug.cgi?id=542986
- Replacing the kernel package is a strong psychological barrier.
  - Can't we somehow try TOMOYO more easily?

What did I think?

- There are functionality which cannot be implemented as a loadable kernel module, for some hooks are not provided by LSM.
  - TOMOYO started as an access analysis tool.
    - For analysis purpose, it would be acceptable that some functionality cannot be implemented?
      - Just try to get used to it.

=> I applied the approach which I established via RWXfilter to TOMOYO 1.8.

Consequence

- We now can use major functionality of TOMOYO 1.8 on Fedora and RHEL kernels.
- Especially useful for analysis purpose because AKARI is a loadable kernel module similar to RWXfilter.
- http://akari.sourceforge.jp/

Access

Keeping

And

Regulating

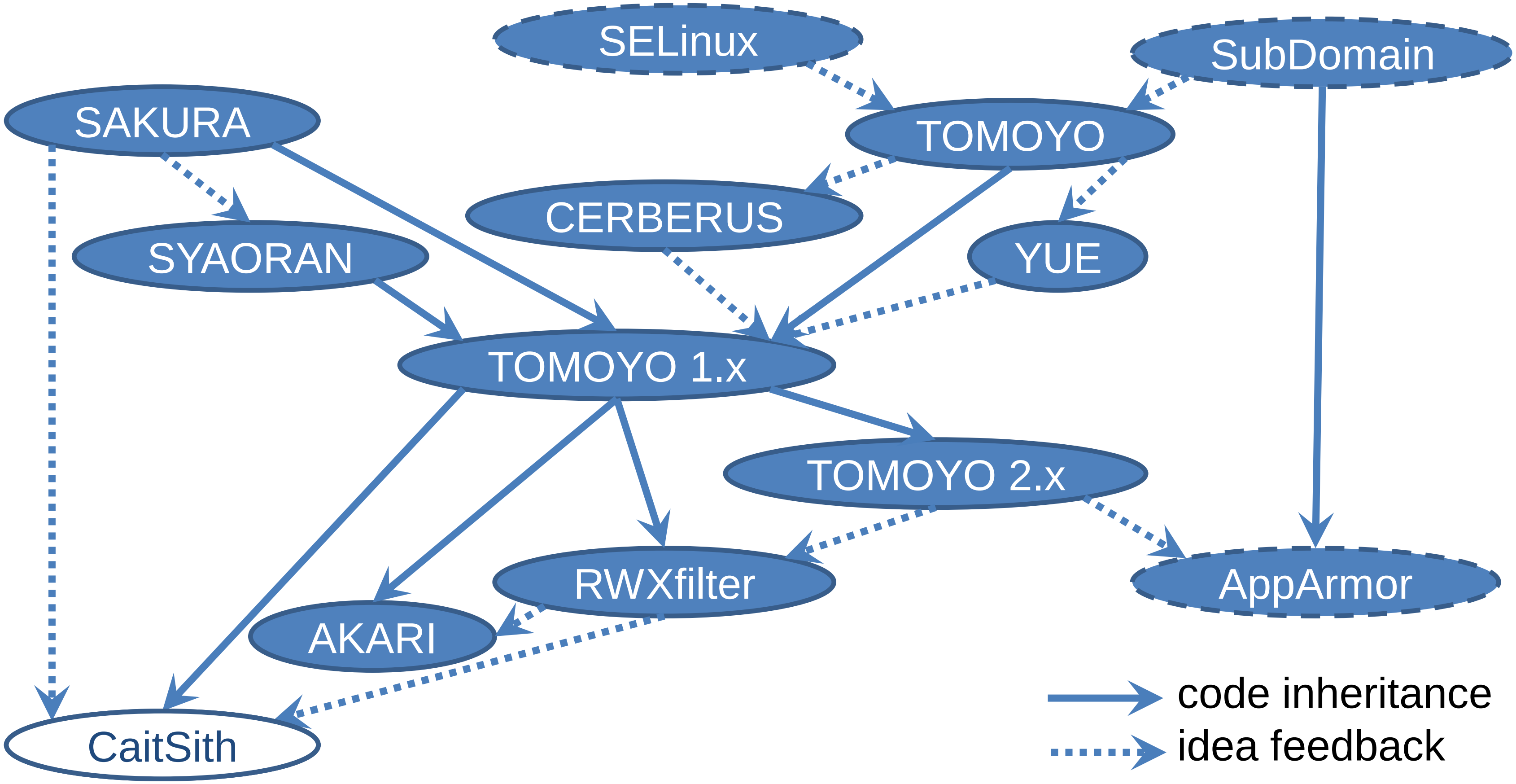
Instrument.

Chapter 4

CaitSith

CaitSith (2012.4-)

- The most powerfully and flexibly configurable policy syntax derived from 9 years of my experience.



Starting point for CaitSith

- Threats are in the behavior of the user space.
  - But the threats are getting to shift to areas where in-kernel access control cannot deal with.
    - For example, mails/tweets by error exposed to or shared by unexpected peers because of bugs in the user space applications.
    - It's a limitation for in-kernel access control.
- The "seccomp mode 2" became available in Linux 3.5.

  => Maybe we no longer need to go off the deep end at the kernel side.

What is the way MAC needs to be?

- Things I experienced with continuing enhancement of access control functionality:
  - A per-domain basis access control can do better than system wide access control, as long as access control is applied on all domains.

    => If there is a domain which access control is not applied, it becomes a hole which would not have existed if system wide access control is used.
  - In reality, there are usually domains which access control is not applied.

    => But system wide access control alone is not sufficient.

What is the way MAC needs to be?

- Things I experienced with continuing enhancement of access control functionality:
  - There are users who want to restrict access using blacklisting approach rather than whitelisting approach.

    => Blacklisting approach is difficult for TOMOYO because TOMOYO automatically creates domain.

What is the way MAC needs to be?

- Things I experienced with continuing enhancement of ease of use:
  - There are users who want to restrict access from the point of view of resources rather than that of processes.

    => Access controls which depends on "define domains first" cannot handle this request.
  - There are users who want to restrict access on specific resources.

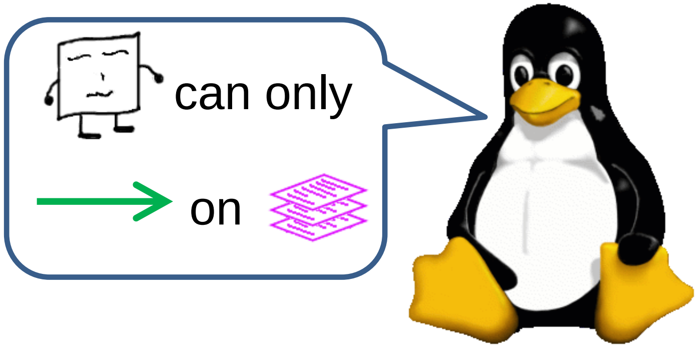
    => Access controls which depends on whitelisting cannot handle this request.

What is the way MAC needs to be?

- My conclusion:
  - It's time to break dependence on domains (Domain Type Enforcement) and whitelisting.
  - Let's consider from scratch.

How can I take advantage of both approaches?

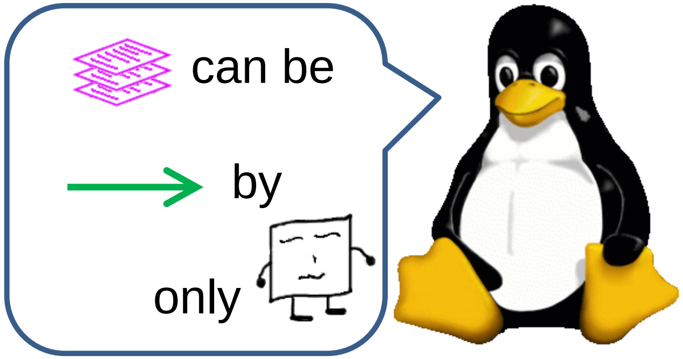
- TOMOYO which was made from the point of view of **subjects** and focused on enhancing functionality



can only

on

- RWXfilter which was made from the point of view of **objects** and focused on enhancing usability



can be

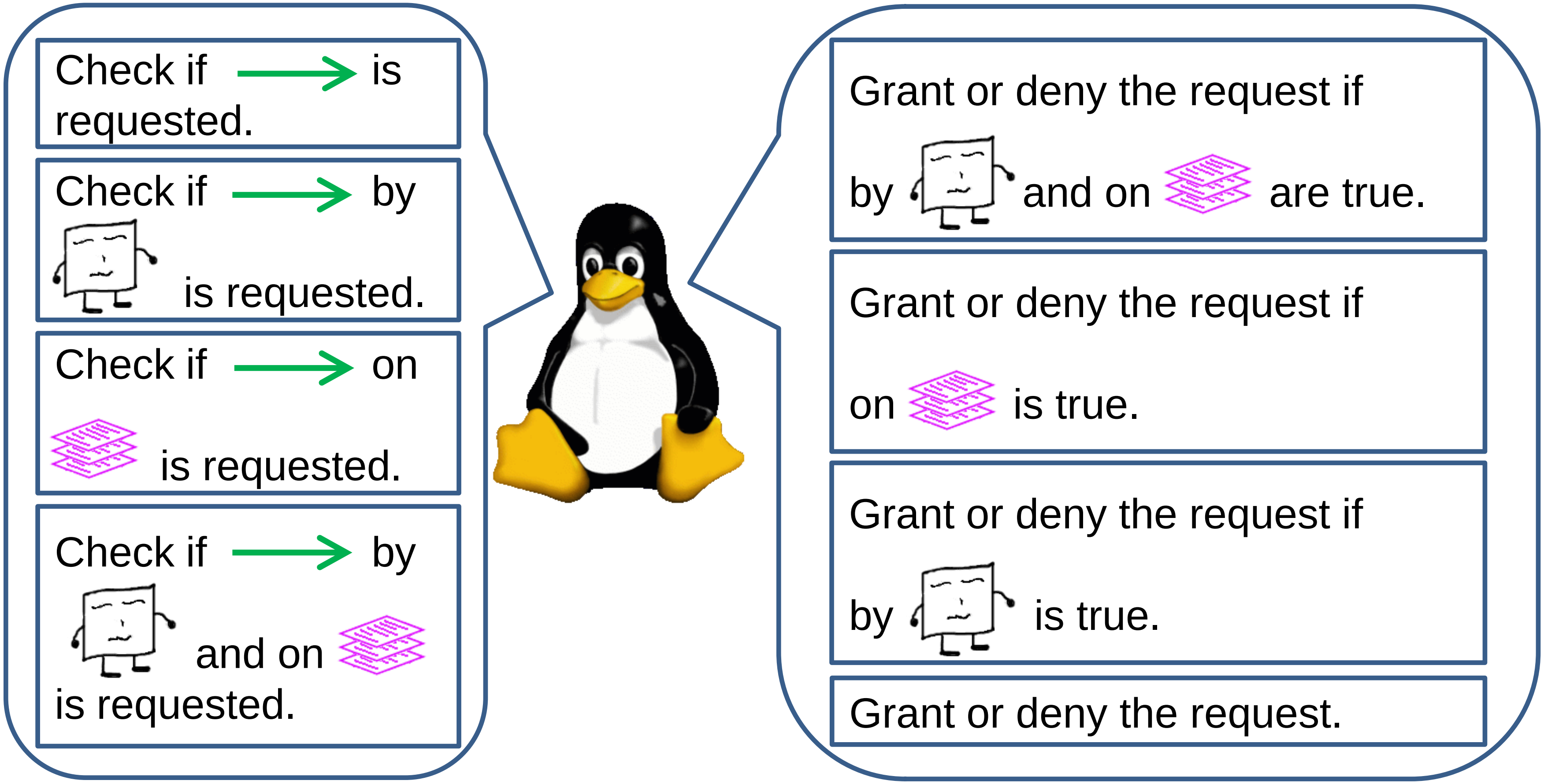
by

only

Why not to use Action as a key?

- Capability model + Access control list model

  => Action check list model



Check if → is requested.

Check if → by 📄 is requested.

Check if → on 🗐 is requested.

Check if → by 📄 and on 🗐 is requested.

Grant or deny the request if by 📄 and on 🗐 are true.

Grant or deny the request if on 🗐 is true.

Grant or deny the request if by 📄 is true.

Grant or deny the request.

My proposed syntax

-
  ```
  acl "Action" "Whether to check Action or not"
          audit "Audit pattern specifier"
          "Decision1" "Whether to use Decision1 or not"
          "Decision2" "Whether to use Decision2 or not"
          "Decision3" "Whether to use Decision3 or not"
  ```
- Specify Action as a key, and enumerate conditions as needed.
  - Not using mandatory (positional) parameters
  - All parameters (including domains) are optional.
- Split into two phases: "whether to check or not" and "whether to grant/deny or not".
  - Not using profiles because there is no need to specify enabled/disabled.

Characteristic points of proposed syntax

- Supports both whitelisting approach and blacklisting approach.
- Supports both the point of view of subjects and the point of view of objects, using actions as a key.
- Allows users to fully utilize TOMOYO's parameter validation capabilities.
- Allows users to apply single function restrictions like RWXfilter.
- Allows users to easily apply system wide restriction because action is the key.

=> Above topics are explained later using example policy.

How does policy file look like?

```
POLICY_VERSION=20120401
quota memory audit 16777216
quota memory query 1048576
quota audit[1] allowed=0 denied=1024 unmatched=1024

0 acl modify_policy
    audit 1
    1 deny task.uid!=0
    1 deny task.euid!=0
    100 allow task.exe="/usr/sbin/caitsith-loadpolicy"
    100 allow task.exe="/usr/sbin/caitsith-queryd"
    10000 deny
```

How does policy file look like?

```
POLICY_VERSION=20120401
quota memory audit 16777216
quota memory query 1048576
quota audit[1] allowed=0 denied=1024 unmatched=1024
```

Header part defines quota and groups

```
0 acl modify_policy
    audit 1
    1 deny task.uid!=0
    1 deny task.euid!=0
    100 allow task.exe="/usr/sbin/caitsith-loadpolicy"
    100 allow task.exe="/usr/sbin/caitsith-queryd"
    10000 deny
```

Body part defines rules

How does policy file look like?

```
POLICY_VERSION=20120401
quota memory audit 16777216
quota memory query 1048576
quota audit[1] allowed=0 denied=1024 unmatched=1024

0 acl modify_policy
    audit 1
    1 deny task.uid!=0
    1 deny task.euid!=0
    100 allow task.exe="/usr/sbin/caitsith-loadpolicy"
    100 allow task.exe="/usr/sbin/caitsith-queryd"
    10000 deny
```

Version of policy syntax

Allow up to 16MB of kernel memory for spooling audit logs

How does policy file look like?

```
POLICY_VERSION=20120401
quota memory audit 16777216
quota memory query 1048576
quota audit[1] allowed=0 denied=1024 unmatched=1024

0 acl modify_policy
    audit 1
    1 deny task.uid!=0
    1 deny task.euid!=0
    100 allow task.exe="/usr/sbi
    100 allow task.exe="/usr/sbi
    10000 deny
```

Apply audit log quota defined in audit[1] line

Allow spooling up to 0 logs when matched "allow" line, up to 1024 logs when matched "deny" line, up to 1024 logs when did not match "allow" line nor "deny" line

How does policy file look like?

```
POLICY_VERSION=20120401
quota memory audit 16777216
quo            1] allowed=0 denied=1024 unmatched=1024

0 acl modify_policy
    audit 1
    1 deny t     .uid!=0
    1 den        .euid!=0
    100          ask.exe="/u
                                      sith-queryd"
```

Checking priority when there are multiple acl blocks with the same action

Additional conditions for checking whether to check this action or not. Unconditionally checked if omitted

Name of action to check. In this example, changing policy configuration

How does policy file look like?

```
POLICY_VERSION=20120401
quota memory audit 16777216
quota memory query 1048576
                                nmatched=1024

0 acl m        policy
    audi
    1 deny task.uid!=0
    1 deny task.euid!=0
    100 allow task.exe="/usr/sbin/caitsith-loadpolicy"
    100 allow task.exe="/usr/sbin/caitsith-queryd"
    10000 deny
```

Decision priority when there are multiple decision lines within this acl block

How does policy file look like?

```
POLICY_VERSION=20120401
quota memory audit 16777216
quota memory query 1048576
quota audit[1] allowed=0 denied=1024 unmatched=1024

0 acl modify_p
    audit 1
    1 deny task.uid!=0
    1 deny task.euid!=0
    100 allow task.exe="/usr/sbin/caitsith-loadpolicy"
    100 allow task.exe="/usr/sbin/caitsith-queryd"
    10000 deny
```

Decision is either "allow" or "deny"

How does policy file look like?

```
POLICY_VERSION=20120401
quota memory audit 16777216
quota memory query 1048576
quota audit[1] allowed=0 denied=1024 unmatched=1024

0 acl modify_policy
    audit 1
    1 deny task.uid!=0
    1 deny task.euid!=0
    100 allow task.exe="/usr/sbin/caitsith-loadpolicy"
    100 allow task.exe="/usr/sbin/caitsith-queryd"
    10000 deny
```

Additional conditions for deciding whether to apply the decision or not.
The decision is unconditionally applied if omitted

How does policy file look like?

```
POLICY_VERSION=20120
quota memory audit 16777
quota memory query 10485
quota audit[1] allowed=0 de

0 acl modify_policy
    audit 1
    1 deny task.uid!=0
    1 deny task.euid!=0
    100 allow task.exe="/usr/sbin/caitsith-loadpolicy"
    100 allow task.exe="/usr/sbin/caitsith-queryd"
    10000 deny
```

This acl block defines below rules.

(1) Deny changing policy configuration if current thread's user id or effective user id is not 0

(2) Allow changing policy configuration if /proc/self/exe is either /usr/sbin/caitsith-loadpolicy or /usr/sbin/caitsith-queryd

(3) Deny changing policy configuration otherwise

How does audit log look like?

- Trying to modify policy configuration by bash will be denied.

```
# echo '1000 acl modify_policy' > /proc/caitsith/policy
-bash: echo: write error: Operation not permitted
```

- And a denied log will be generated.

```
0 acl modify_policy
    audit 1
    1 deny task.uid!=0
    1 deny task.euid!=0
    100 allow task.exe="/usr/sbin/caitsith-loadpolicy"
    100 allow task.exe="/usr/sbin/caitsith-queryd"
    10000 deny
```

Doesn't match

Doesn't match

Doesn't match

Doesn't match

Matches

How does audit log look like?

- Below is a denied log generated by trying to modify policy configuration by bash.

```
#2012/07/11 14:06:21# global-pid=3584 result=denied
priority=0 / modify_policy task.pid=3584 task.ppid=3582
task.uid=0 task.gid=0 task.euid=0 task.egid=0 task.suid=0
task.sgid=0 task.fsuid=0 task.fsgid=0
task.type!=execute_handler task.exe="/bin/bash"
task.domain="/usr/sbin/sshd"
```

This log is readable from /proc/caitsith/audit and is saved by caitsith-auditd program

How does audit log look like?

- Below is a denied log generated by trying to modify policy configuration by bash.

  -
    ```
    #2012/07/11 14:06:21# global-pid=3584 result=denied priority=0 / modify_policy task.pid=3584 task.ppid=3582 task.uid=0 task.gid=0 task.euid=0 task.egid=0 task.suid=0 task.sgid=0 task.fsuid=0 task.fsgid=0 task.type!=execute_handler task.exe="/bin/bash" task.domain="/usr/sbin/sshd"
    ```

This log was generated by "0 acl modify_policy" block

Result is one of "allowed" or "denied" or "unmatched"

How does audit log look like?

- Below is a denied log generated by trying to modify policy configuration by bash.

  -
    ```
    #2012/07/11 14:06:21# global-pid=3584 result=denied priority=0 / modify_policy task.pid=3584 task.ppid=3582 task.uid=0 task.gid=0 task.euid=0 task.egid=0 task.suid=0 task.sgid=0 task.fsuid=0 task.fsgid=0 task.type!=execute_handler task.exe="/bin/bash" task.domain="/usr/sbin/sshd"
    ```

These are variables within the access request.
These variables can be used as conditions as needed

How to update policy?

- Trying to modify policy configuration by caitsith-loadpolicy will be allowed.

```
# (echo '0 acl modify_policy'; echo '1 deny task.gid!=0') |
   /usr/sbin/caitsith-loadpolicy
```

- But an allowed log will not be generated.

```
0 acl modify_policy
    audit 1
    1 deny task.uid!=0
    1 deny task.euid!=0
    100 allow task.exe="/usr/sbin/caitsith-loadpolicy"
    100 allow task.exe="/usr/sbin/caitsith-queryd"
    10000 deny
```

Doesn't match

Doesn't match

Matches

How does user space daemon work?

```
POLICY_VERSION=20120401
quota memory audit 16777216
quota memory query 1048576
quota audit[1] allowed=0 denied=1024 unmatched=1024

0 acl modify_policy
    audit 1
    1 deny task.uid!=0
    1 deny task.euid!=0
    100 allow task.exe="/usr/sbin/caitsith-loadpolicy"
    100 allow task.exe="/usr/sbin/caitsith-queryd"
    10000 deny
```

Allow up to 1MB of kernel memory for spooling access requests waiting for interactive judgment when caitsith-queryd program is running

How does user space daemon work?

```
POLICY_VERSION=20120401
quota memory audit 16777216
quota memory query 1
quota audit[1] allowed=

0 acl modify_policy
    audit 1
    1 deny task.uid!=0
    1 deny task.euid!=0
    100 allow task.exe="/usr/sbin/caitsith-loadpolicy"
    100 allow task.exe="/usr/sbin/caitsith-queryd"
    10000 deny
```

A denied log is generated and then access request is spooled for interactive judgment. If caitsith-queryd allows, the permission check continues as if the access request did not match the "deny" line. The access request is denied otherwise

How does user space daemon work?

- Below is a query shown by caitsith-queryd program.

```
#2012/07/11 14:06:21# global-pid=3584 result=denied priority=0 / modify_policy task.pid=3584 task.ppid=3582 task.uid=0 task.gid=0 task.euid=0 task.egid=0 task.suid=0 task.sgid=0 task.fsuid=0 task.fsgid=0 task.type!=execute_handler task.exe="/bin/bash" task.domain="/usr/sbin/sshd"
Allow? ('Y'es/'N'o/'R'etry/'S'how policy/'A'dd to policy and retry):
```

Identical with audit log, except that a prompt line for manual decision is shown.

Characteristic points of proposed syntax

- Supports both whitelisting approach and blacklisting approach.

```
1000 acl execute task.exe="/usr/sbin/httpd"
    audit 1
    100 allow path="/var/www/cgi-bin/counter.cgi"
    200 deny
```

whitelisting approach ends with an unconditional "deny" line

```
2000 acl execute task.exe="/usr/sbin/httpd"
    audit 1
    100 deny path="/bin/sh"
    200 allow
```

blacklisting approach ends with an unconditional "allow" line

Characteristic points of proposed syntax

- Supports both the point of view of subjects and the point of view of objects, using actions as a key.

```
1000 acl execute task.exe="/usr/sbin/httpd"
    audit 1
    100 allow path="/usr/sbin/suexec"
    200 deny
```

/usr/sbin/httpd can execute only /usr/sbin/suexec

```
2000 acl execute path="/usr/sbin/suexec"
    audit 1
    100 allow task.exe="/usr/sbin/httpd"
    200 deny
```

/usr/sbin/suexec can be execute by only /usr/sbin/httpd

Characteristic points of proposed syntax

- Supports both the point of view of subjects and the point of view of objects, using actions as a key.

```
1000 acl inet_stream_listen task.exe="/usr/sbin/sshd"
    audit 1
    100 allow port=22
    200 deny
```

/usr/sbin/sshd can listen to TCP sockets at only port 22

```
2000 acl inet_stream_listen port=22
    audit 1
    100 allow task.exe="/usr/sbin/sshd"
    200 deny
```

TCP socket's port 22 can be listened by only /usr/sbin/sshd

Characteristic points of proposed syntax

- Allows users to fully utilize TOMOYO's parameter validation capabilities.

Check ioctl requests on /dev/kvm device

```
0 acl ioctl path.type=char path.dev_major=10 path.dev_minor=232
 audit 1
 100 deny task.exe!="/usr/libexec/qemu-kvm"
 200 allow cmd=@PERMITTED_DEV_KVM_IOCTL_CMD_NUMBERS
 300 deny
```

Only /usr/libexec/qemu-kvm can issue ioctl requests on /dev/kvm device

Only ioctl command numbers defined by "number_group PERMITTED_DEV_KVM_IOCTL_CMD_NUMBERS" lines in the header part of policy file are permitted

Characteristic points of proposed syntax

- Allows users to apply single function restrictions like RWXfilter.

Check TCP socket's connect requests

Only port numbers defined by "number_group PERMITTED_INET_CONNECT_PORTS" lines are permitted

```
1000 acl inet_stream_connect
    audit 1
    100 deny port!=@PERMITTED_INET_CONNECT_PORTS
    100 allow
    ip=@PERMITTED_INET_CONNECT_ADDRESSES
    200 deny
```

Only IPv4/IPv6 addresses defined by "ip_group PERMITTED_INET_CONNECT_ADDRESSES" lines are permitted

Characteristic points of proposed syntax

- Allows users to easily apply system wide restriction because action is the key.

Only /bin/mount can issue mount requests

```
100 acl mount
    audit 1
    0 deny task.exe!="/bin/mount"
    1 allow target="/proc/" fstype="proc" flags=0x0
    1 allow target="/sys/" fstype="sysfs" flags=0x0
    1 allow target="/dev/pts/" fstype="devpts" flags=0x0
    1 allow target="/dev/shm/" fstype="tmpfs" flags=0x0
    1 allow target="/" fstype="--remount" flags=0x1
    1 allow target="/" fstype="--remount" flags=0x400
    2 deny
```

How to use CaitSith?

- Installation steps are almost same with those of TOMOYO 1.8.
  - Because CaitSith shares same kernel patches used by TOMOYO 1.8.
  - Applying kernel patches is easy because most of hooks are already embedded into LSM.

- Usage steps are

  (1) Define acl blocks you want to check

  (2) Edit decision lines in the blocks from audit logs

  (3) Terminate the blocks with unconditional deny (or allow) line

Please try CaitSith.

- http://caitsith.sourceforge.jp/

  Characteristic

  action

  inspection

  tool.

  See

  if

  this

  helps.