Protecting system integrity with Trusted Platform Module

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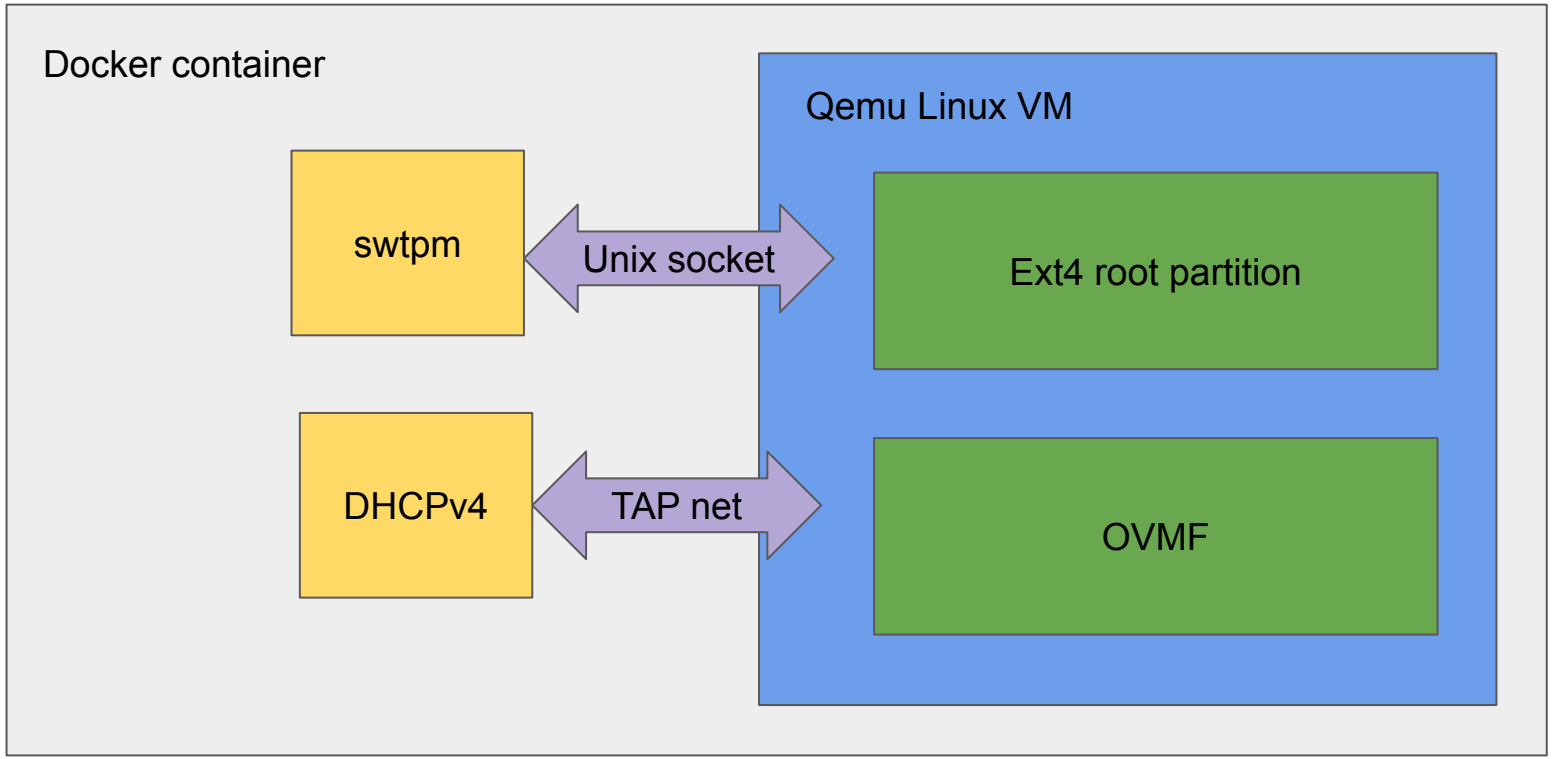
FACEBOOK

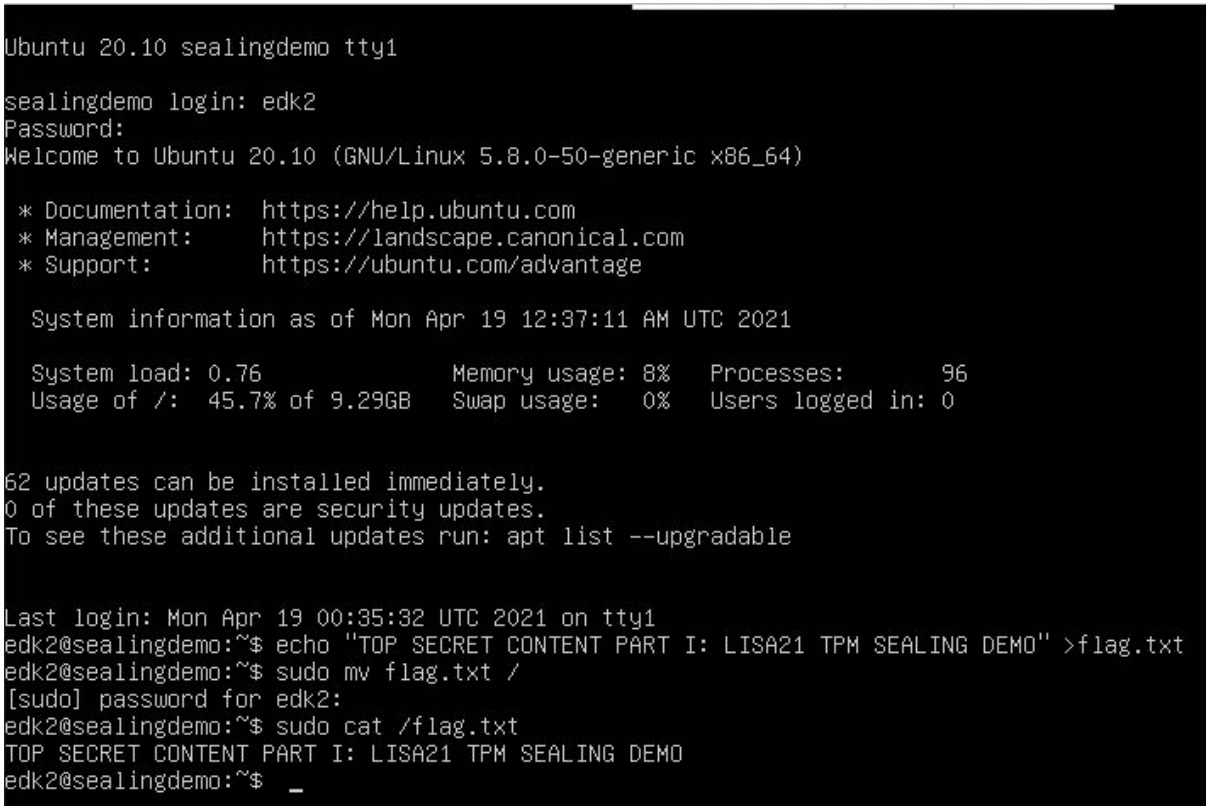
Agenda

- Setup description
- Compromising secret using demo DXE malicious driver
- Using measured boot and TPM sealing capabilities to prevent the attack
- Q&A

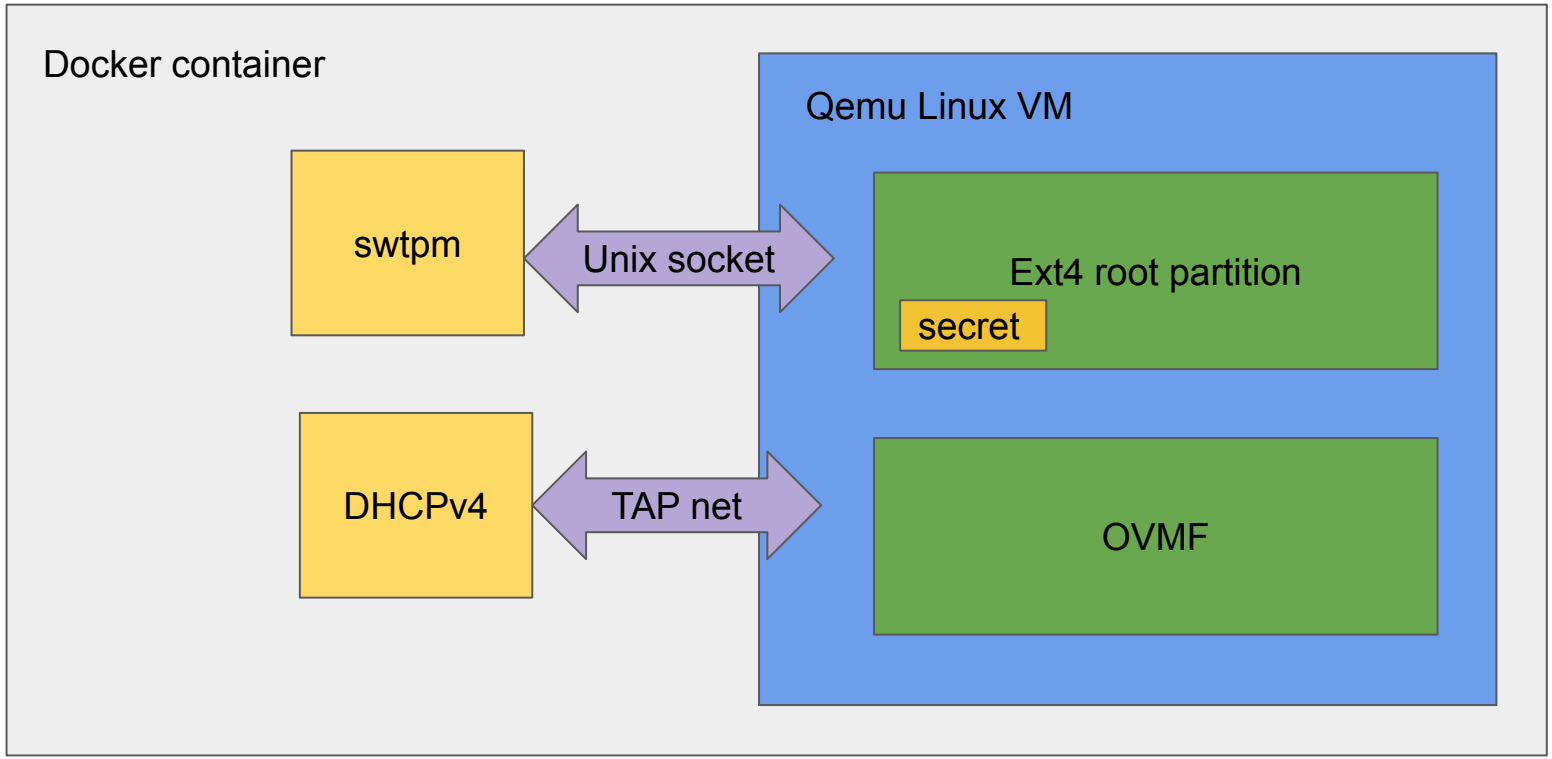
Setup


Docker container
Qemu Linux VM
swtpm
Unix socket
Ext4 root partition
DHCPv4
TAP net
OVMF

Creating a secret



Setup


Docker container
Qemu Linux VM
swtpm
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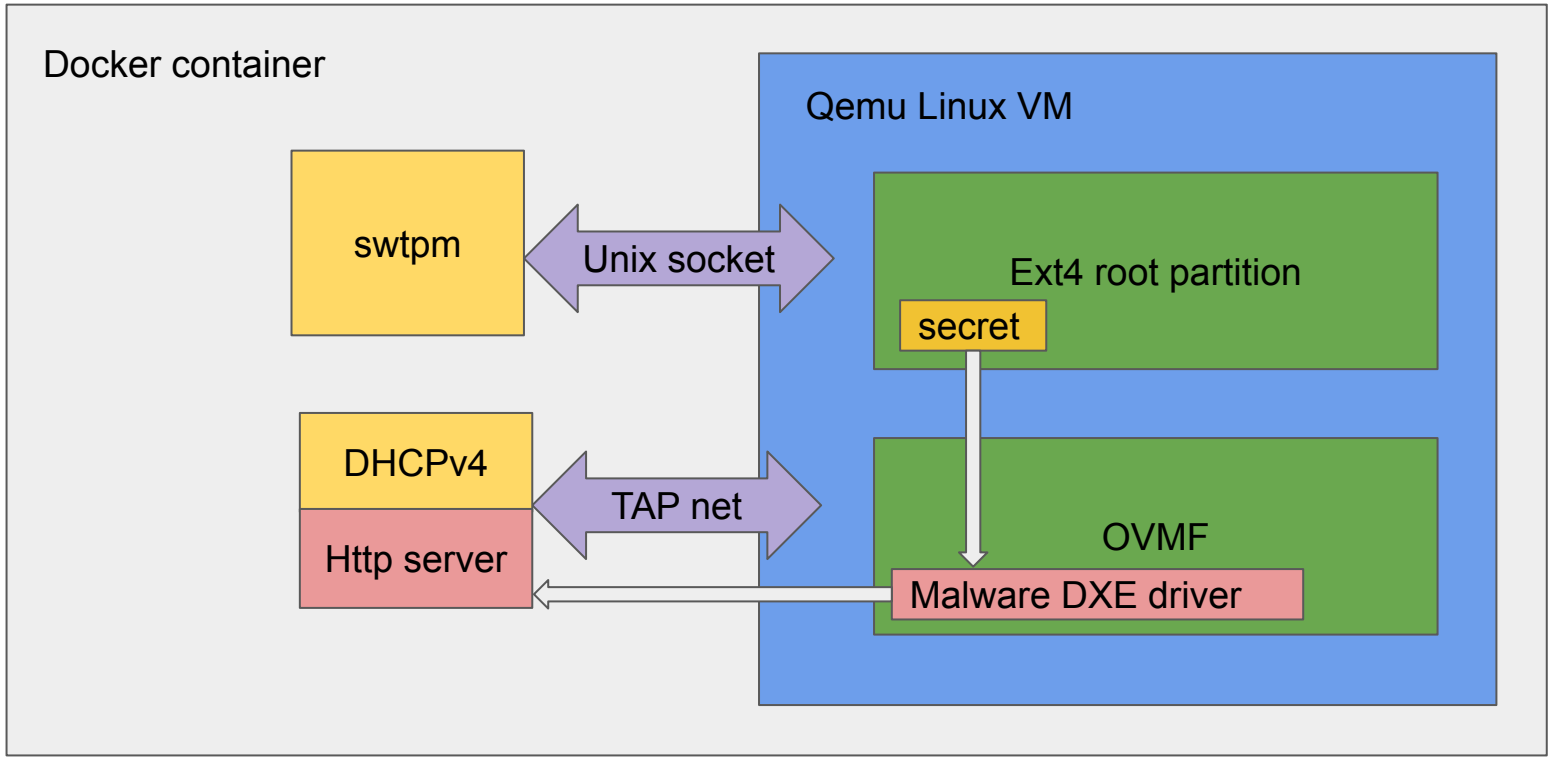
secret
DHCPv4
TAP net
OVMF

Setup


Docker container
Qemu Linux VM
swtpm
Unix socket
Ext4 root partition
secret
DHCPv4
Http server
TAP net
OVMF
Malware DXE driver

Malware at work

```
[FbM] Locating handle for FileSystem protocol
[FbM] Could not open FileSystem protocol on handle 0, trying next
[FbM] secret found:TOP SECRET CONTENT PART I: LISA21 TPM SEALING DEMO
[FbM] Running DHCPv4 2
[FbM] Dhcp4 starting
[FbM] Interface name is: eth0
[FbM] Sending the secret to external host
[FbM] HTTP Request successful, getting response
[FbM] ReadyToBoot done
BdsDxe: loading Boot0007 "ubuntu" from HD(1,GPT,DEA400E6-5F8A-4D34-AC83-B9BBAE3A
6065,0x800,0x100000)/\EFI\ubuntu\shimx64.efi
BdsDxe: starting Boot0007 "ubuntu" from HD(1,GPT,DEA400E6-5F8A-4D34-AC83-B9BBAE3
A6065,0x800,0x100000)/\EFI\ubuntu\shimx64.efi
```


```
edk2@677244790add:~$ python3 malware_server.py
Headers: content-length: 49


Data: TOP SECRET CONTENT PART I: LISA21 TPM SEALING DEMO
192.168.30.53 - - [19/Apr/2021 08:57:08] "POST / HTTP/1.1" 200 -
All done!
```

Example malicious DXE driver

- Created using EDK II
- ~ 700 LOC in C
- DHCPv4/v6 support
- Ext2/3/4 filesystem support
- ~ 16Kb compiled, and ~200Kb of support DXE drivers (libraries)
- Tested on real hardware

EDK II

- Open Source firmware development environment
- Among other things, allows to build UEFI DXE drivers
- Used to build our “demo malware”

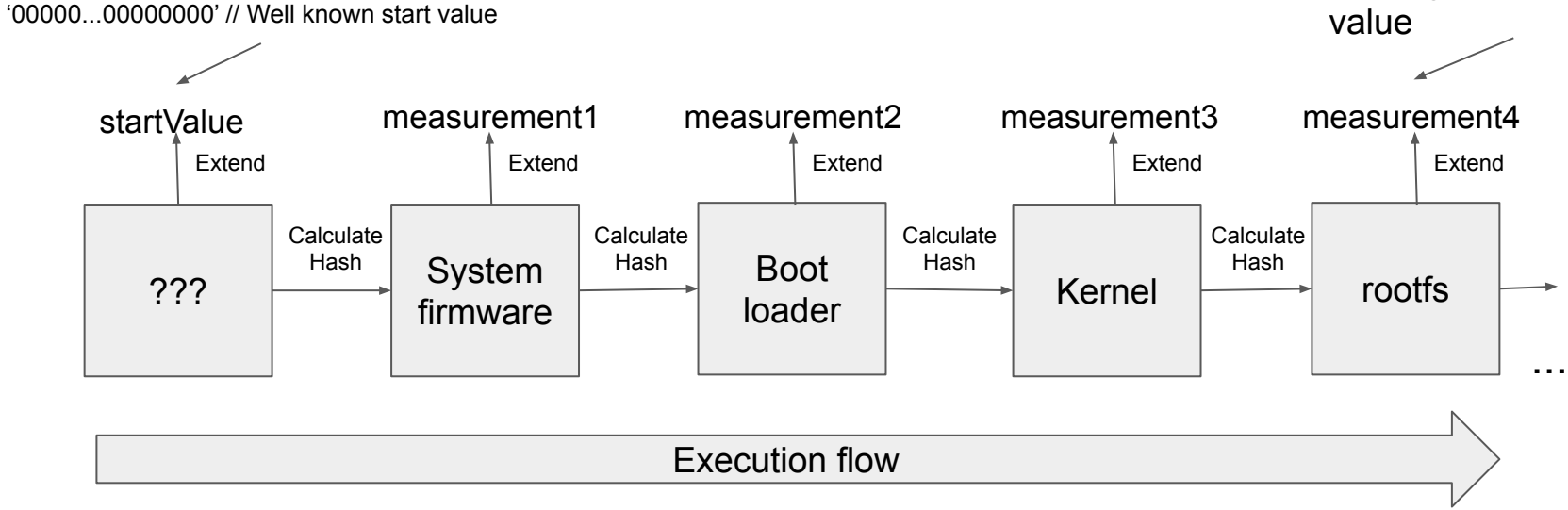
Could Secure Boot help?

- Yes, in some cases...
- Doesn’t scale well - flash memory bitflips and human errors can cause big problems
- How to make sure that it’s enabled and uses a right key?

Measured boot

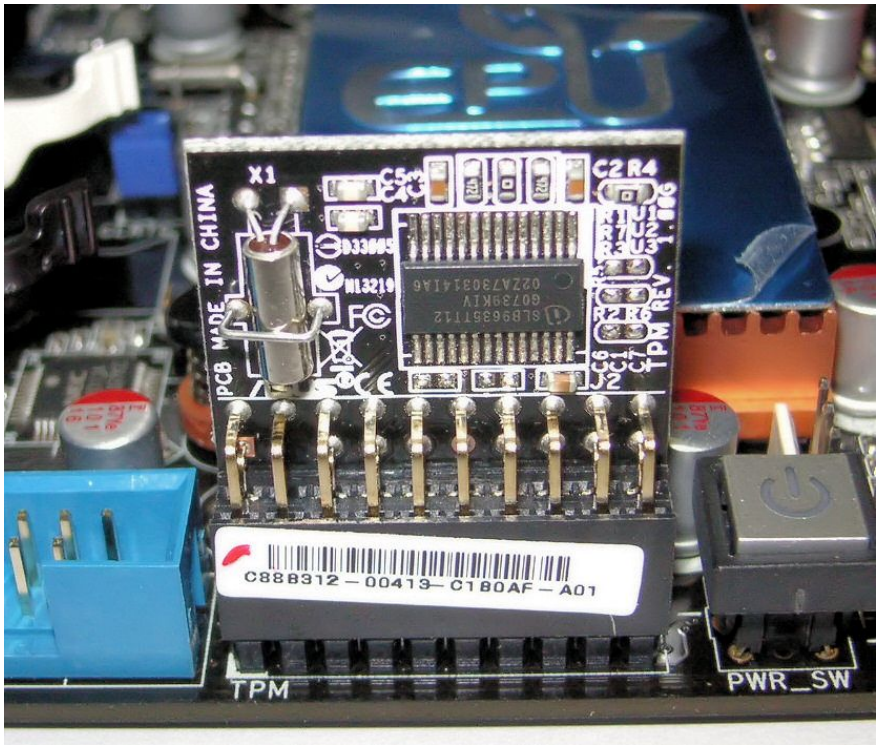
```
func extendHash(current_value, extension) {
    return SHA256(current_value | SHA256(extension))
}
```

The last measurement in the chain depends on all previous ones, starting from the initial value



Trusted Platform Module

- Hardware storage of measurements - Platform Configuration Registers (PCRs)
- Allows only “extension”, there is no way to change PCR values directly
- Is able to export and sign list of PCR values - create a “Quote”
- Has a unique identity which allows to check if the Quote came from a real chip



Measured boot with sealing approach

- Do remote attestation
- Deliver the secret to the system
- Seal the secret to the “authorize” policy
- Check that the system state during sealing matches the one after attestation
- Deliver a signed policy which allows the secret to be unsealed only in a known good state
- Use the signed policy to unseal the secret after system reboots

Measured boot with sealing approach

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These we will demonstrate

Generation of policy signing key

```
edk2@sealingdemo:~/sealing_demo$ mkdir policy_signing_key
edk2@sealingdemo:~/sealing_demo$ cd policy_signing_key/
edk2@sealingdemo:~/sealing_demo/policy_signing_key$ openssl genrsa -out priv.pem 2048
Generating RSA private key, 2048 bit long modulus (2 primes)
.............................................+++++
..............+++++
e is 65537 (0x010001)
edk2@sealingdemo:~/sealing_demo/policy_signing_key$ openssl rsa -in priv.pem -out pub.pem -pubout
writing RSA key
edk2@sealingdemo:~/sealing_demo/policy_signing_key$ ls
priv.pem  pub.pem
edk2@sealingdemo:~/sealing_demo/policy_signing_key$ tpm2_loadexternal -G rsa -C o -u pub.pem -c key.ctx -n pub.name
name: 000bd3ad44ca46cff35a4c0ac7b5f0d3ec449525cfa5a8065676246294f10d5f5a0f
edk2@sealingdemo:~/sealing_demo/policy_signing_key$ ls
key.ctx  priv.pem  pub.name  pub.pem
edk2@sealingdemo:~/sealing_demo/policy_signing_key$ rm -f key.ctx
edk2@sealingdemo:~/sealing_demo/policy_signing_key$ _
```

Authorize policy creation

```
edk2@sealingdemo:~/sealing_demo/policy_signing_key$
edk2@sealingdemo:~/sealing_demo/policy_signing_key$ cd ..
edk2@sealingdemo:~/sealing_demo$ tpm2_startauthsession -S auth.ctx
edk2@sealingdemo:~/sealing_demo$ tpm2_policyauthorize -S auth.ctx -L authorized.policy -n ./policy_signing_key/pub.name
293b976e35f97ee6668aec36d9e74c4b73d34912962c92cb65a5acfb8b6dd14e
edk2@sealingdemo:~/sealing_demo$ tpm2_flushcontext auth.ctx
edk2@sealingdemo:~/sealing_demo$ rm -f auth.ctx
edk2@sealingdemo:~/sealing_demo$ ls
authorized.policy  policy_signing_key
edk2@sealingdemo:~/sealing_demo$
```

Sealing the secret

```
edk2@sealingdemo:~/sealing_demo$
edk2@sealingdemo:~/sealing_demo$ tpm2_createek -c ek.ctx
edk2@sealingdemo:~/sealing_demo$ tpm2_startauthsession --policy-session -S auth.ctx
edk2@sealingdemo:~/sealing_demo$ tpm2_policysecret -S auth.ctx -c e
837197674484b3f81a90cc8d46a5d724fd52d76e06520b64f2a1da1b331469aa
edk2@sealingdemo:~/sealing_demo$ echo "TOP SECRET CONTENT PART II: LISA21 TPM SEALING DEMO" | tpm2_create -g sha256 -u secret.pu
b -r secret.priv -i- -C ek.ctx -L authorized.policy -P "session:auth.ctx"
name-alg:
  value: sha256
  raw: 0xb
attributes:
  value: fixedtpm|fixedparent
  raw: 0x12
type:
  value: keyedhash
  raw: 0x8
algorithm:
  value: null
  raw: 0x10
keyedhash: 09b8ccae1d7a356af75dfc18a60223971c05c2da30ec3f4c2502a5478a560991
authorization policy: 293b976e35f97ee6668aec36d9e74c4b73d34912962c92cb65a5acfb8b6dd14e
edk2@sealingdemo:~/sealing_demo$ tpm2_flushcontext auth.ctx
edk2@sealingdemo:~/sealing_demo$ ls
auth.ctx  authorized.policy  ek.ctx  policy_signing_key  secret.priv  secret.pub
edk2@sealingdemo:~/sealing_demo$ rm -f auth.ctx ek.ctx authorized.policy
edk2@sealingdemo:~/sealing_demo$ ls
policy_signing_key  secret.priv  secret.pub
edk2@sealingdemo:~/sealing_demo$
```

Is it really encrypted? :)

```
edk2@sealingdemo:~/sealing_demo$
edk2@sealingdemo:~/sealing_demo$ xxd secret.priv
00000000: 00b2 0020 cef8 afff ac8c 5a11 9856 f9b6  ... ......Z..V..
00000010: fe50 b919 4d9b 0f80 d3ee 82e4 0d4c b9a2  .P..M........L..
00000020: a997 7313 0010 eff3 366e 7996 81c7 a0bc  ..s.....6ny.....
00000030: 3cc1 9972 c24f db83 6602 663f 569e 61ed  <..r.O..f.f?V.a.
00000040: 570c ac81 b6fd ceba c688 ec43 cb03 dc50  W..........C...P
00000050: 57af 1d9e f8b1 47f6 b0e6 b875 9098 5e13  W.....G....u..^.
00000060: cd1b d8e1 ca3c b889 1fa9 a14b c79b 79be  .....<.....K..y.
00000070: 0ede 15f5 1331 728c 3c80 ede8 43a6 e74c  .....1r.<...C..L
00000080: 98cd 0b05 fb9a dca2 7caf acb6 eb8a ef42  ........|......B
00000090: 1efe 5e58 ad08 fa8e 7418 9359 63c8 8e48  ..^X....t..Yc..H
000000a0: 261a ce1a ec8e 4027 60b8 dd4b 86ba c8e8  &.....@'`..K....
000000b0: d5e3 637b                                ..c{
edk2@sealingdemo:~/sealing_demo$ xxd secret.pub
00000000: 004e 0008 000b 0000 0012 0020 293b 976e  .N......... );.n
00000010: 35f9 7ee6 668a ec36 d9e7 4c4b 73d3 4912  5.~.f..6..LKs.I.
00000020: 962c 92cb 65a5 acfb 8b6d d14e 0010 0020  .,..e....m.N...
00000030: 09b8 ccae 1d7a 356a f75d fc18 a602 2397  .....z5j.]....#.
00000040: 1c05 c2da 30ec 3f4c 2502 a547 8a56 0991  ....0.?L%..G.V..
edk2@sealingdemo:~/sealing_demo$
edk2@sealingdemo:~/sealing_demo$ ls
policy_signing_key  secret.priv  secret.pub
edk2@sealingdemo:~/sealing_demo$
edk2@sealingdemo:~/sealing_demo$ _
```

Creating PCR policy

TODO

- Obtain PCR values, which match a desired system state.
- Generate the PCR policy
- Sign it with the policy signing key
- Deliver to the system

Creating PCR policy

```
edk2@sealingdemo:~/sealing_demo$
edk2@sealingdemo:~/sealing_demo$ tpm2_pcrread -o pcr.dat "sha1:0"
sha1:
  0 : 0x5564B9D251554FC4DB5F8B1D5C94F1360EA7E51F
edk2@sealingdemo:~/sealing_demo$ xxd pcr.dat
00000000: 5564 b9d2 5155 4fc4 db5f 8b1d 5c94 f136  Ud..QUO.._..\..6
00000010: 0ea7 e51f                                ....
edk2@sealingdemo:~/sealing_demo$ ls
pcr.dat  policy_signing_key  secret.priv  secret.pub
edk2@sealingdemo:~/sealing_demo$ tpm2_startauthsession -S auth.ctx
edk2@sealingdemo:~/sealing_demo$ tpm2_policypcr -S auth.ctx -l sha1:0 -f pcr.dat -L pcr0.sha1.policy
5571ed199aa5f459a4e324ea9795a8aaf41b4a8dda61d8f85b5706580b2a3b65
edk2@sealingdemo:~/sealing_demo$ tpm2_flushcontext auth.ctx
edk2@sealingdemo:~/sealing_demo$ openssl dgst -sha256 -sign ./policy_signing_key/priv.pem -out pcr_policy.signature pcr0.sha1.po
licy
edk2@sealingdemo:~/sealing_demo$ ls
auth.ctx  pcr0.sha1.policy  pcr.dat  pcr_policy.signature  policy_signing_key  secret.priv  secret.pub
edk2@sealingdemo:~/sealing_demo$ rm -f auth.ctx pcr.dat
edk2@sealingdemo:~/sealing_demo$
```

Unseal the secret

TODO

- Verify policy signature
- Satisfy PCR policy
- Satisfy Authorize policy
- Load the sealed secret to TPM
- Actually unseal the secret

Unseal the secret

Verify PCR policy signature

```
edk2@sealingdemo:~/sealing_demo$ tpm2_loadexternal -G rsa -C o -u ./policy_signing_key/pub.pem -c psk.ctx
name: 000bd3ad44ca46cff35a4c0ac7b5f0d3ec449525cfa5a8065676246294f10d5f5a0f
edk2@sealingdemo:~/sealing_demo$ tpm2_verifysignature -c psk.ctx -g sha256 -m pcr0.sha1.policy -s pcr_policy.signature -t verifi
cation.tkt -f rsassa
edk2@sealingdemo:~/sealing_demo$ ls
pcr0.sha1.policy  pcr_policy.signature  policy_signing_key  psk.ctx  secret.priv  secret.pub  verification.tkt
edk2@sealingdemo:~/sealing_demo$ rm -f psk.ctx
```

Satisfy PCR and authorize policies

```
edk2@sealingdemo:~/sealing_demo$ tpm2_startauthsession --policy-session -S auth.ctx
edk2@sealingdemo:~/sealing_demo$ tpm2_policypcr -S auth.ctx -l sha1:0
5571ed199aa5f459a4e324ea9795a8aaf41b4a8dda61d8f85b5706580b2a3b65
edk2@sealingdemo:~/sealing_demo$ tpm2_policyauthorize -S auth.ctx -i pcr0.sha1.policy -n ./policy_signing_key/pub.name -t verifi
cation.tkt
293b976e35f97ee6668aec36d9e74c4b73d34912962c92cb65a5acfb8b6dd14e
edk2@sealingdemo:~/sealing_demo$ ls
auth.ctx  pcr0.sha1.policy  pcr_policy.signature  policy_signing_key  secret.priv  secret.pub  verification.tkt
edk2@sealingdemo:~/sealing_demo$
```

Unseal the secret

Load sealed secret to TPM

```
edk2@sealingdemo:~/sealing_demo$ tpm2_createek -c ek.ctx
edk2@sealingdemo:~/sealing_demo$ tpm2_startauthsession --policy-session -S ek_auth.ctx
edk2@sealingdemo:~/sealing_demo$ tpm2_policysecret -S ek_auth.ctx -c e
837197674484b3f81a90cc8d46a5d724fd52d76e06520b64f2a1da1b331469aa
edk2@sealingdemo:~/sealing_demo$ tpm2_load -C ek.ctx -u secret.pub -r secret.priv -c secret.ctx -P session:ek_auth.ctx
name: 000b9ccadd97edc34614378b3523b411c6cbca0e5a0b37d14bc3068c547bf78b4f3a
edk2@sealingdemo:~/sealing_demo$ tpm2_flushcontext ek_auth.ctx
edk2@sealingdemo:~/sealing_demo$ ls
auth.ctx     ek.ctx           pcr_policy.signature  secret.ctx   secret.pub
ek_auth.ctx  pcr0.sha1.policy  policy_signing_key    secret.priv  verification.tkt
edk2@sealingdemo:~/sealing_demo$ rm -f ek_auth.ctx ek.ctx
```

Unseal the secret

```
edk2@sealingdemo:~/sealing_demo$
edk2@sealingdemo:~/sealing_demo$ tpm2_unseal -p session:auth.ctx -c secret.ctx
TOP SECRET CONTENT PART II: LISA21 TPM SEALING DEMO
edk2@sealingdemo:~/sealing_demo$ tpm2_flushcontext auth.ctx
edk2@sealingdemo:~/sealing_demo$ ls
auth.ctx  pcr0.sha1.policy  pcr_policy.signature  policy_signing_key  secret.ctx  secret.priv  secret.pub  verification.tkt
edk2@sealingdemo:~/sealing_demo$ rm -f auth.ctx secret.ctx
edk2@sealingdemo:~/sealing_demo$ _
```

Boot with malicious firmware and try to satisfy policies

```
edk2@sealingdemo:~/sealing_demo$ tpm2_pcrread sha1:0
sha1:
  0 : 0x19DE21F1C2844E4FDC180288D85384392A40FD74
edk2@sealingdemo:~/sealing_demo$ tpm2_startauthsession --policy-session -S auth.ctx
edk2@sealingdemo:~/sealing_demo$ tpm2_policypcr -S auth.ctx -l sha1:0
d8cb2e28ec827e5dc249edcc234e8529f1aae532acc869961cb4b03c98ec6062
edk2@sealingdemo:~/sealing_demo$ tpm2_policyauthorize -S auth.ctx -i pcr0.sha1.policy -n ./policy_signing_key/pub.name -t verifi
cation.tkt
WARNING:esys:src/tss2-esys/api/Esys_PolicyAuthorize.c:306:Esys_PolicyAuthorize_Finish() Received TPM Error
ERROR:esys:src/tss2-esys/api/Esys_PolicyAuthorize.c:108:Esys_PolicyAuthorize() Esys Finish ErrorCode (0x000001c4)
ERROR: Esys_PolicyAuthorize(0x1C4) - tpm:parameter(1):value is out of range or is not correct for the context
ERROR: Could not build tpm authorized policy
ERROR: Unable to run tpm2_policyauthorize
edk2@sealingdemo:~/sealing_demo$ tpm2_flushcontext auth.ctx
edk2@sealingdemo:~/sealing_demo$ rm -f auth.ctx
edk2@sealingdemo:~/sealing_demo$
```

```
edk2@sealingdemo:~/sealing_demo$
edk2@sealingdemo:~/sealing_demo$ tpm2_pcrread -o pcr.dat "sha1:0"
sha1:
  0 : 0x5564B9D251554FC4DB5F8B1D5C94F1360EA7E51F
edk2@sealingdemo:~/sealing_demo$ xxd pcr.dat
00000000: 5564 b9d2 5155 4fc4 db5f 8b1d 5c94 f136  Ud..QUO.._..\..6
00000010: 0ea7 e51f                                ....
edk2@sealingdemo:~/sealing_demo$ ls
pcr.dat  policy_signing_key  secret.priv  secret.pub
edk2@sealingdemo:~/sealing_demo$ tpm2_startauthsession -S auth.ctx
edk2@sealingdemo:~/sealing_demo$ tpm2_policypcr -S auth.ctx -l sha1:0 -f pcr.dat -L pcr0.sha1.policy
5571ed199aa5f459a4e324ea9795a8aaf41b4a8dda61d8f85b5706580b2a3b65
```

Questions time

Happy sealing! :)

Dmitrii Potoskuev [dpotoskuev@fb.com]