Secure Device Design via Protocol Analysis

By means of an example

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Example: Cryptographically Assured Information Flow

- Secure reprogrammable devices — Even remotely
  - End Cryptographic Units, Key loaders, Enterprise Mgt.
- Reprogrammable counts because:
  - Asymmetric algs may change — Digital Signatures
    e.g. in response to quantum threat
  - Application-level crypto too — ciphers + hashes
  - Other code may evolve — Key mgt

Minimal hardware to ensure
we control our programs and keys on device

Adapted from Trusted Execution Environments

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Adversary model for secure reprogrammability

If we can reprogram it,
maybe the adversary can too?

- Goals preserved even if adversary:
  - installs malicious software on my devices
    or modifies my software maliciously
- Must assure:
  - My data delivered only to my programs — confidentiality
  - My programs act only on my data — integrity
- Payoff for:
  - End Cryptographic Units, Data Transfer Devices, Enterprise mgt

CAIF mechanism: Services

- Services are programs with
  - Isolated address space
  - Unchanging executable code segment
  - Hash of code segment is service identity
- CAIF mechanism maintains hash of code segment
- CAIF uses code hash for:
  - Provenance:

    Who prepared this data for me?

  - Protection:

    Who can receive this data from me?

CAIF mechanism: Instructions

Two pairs of instructions
to control flow between services
as identified by code hash

- For protection + provenance:
  - `protect-for` and `retrieve-from`

    Symmetric authenticated encryption
- For provenance:
  - `attest-locally` and `check-attest`

    Message Authentication Codes
- Focus: `protect-for` / `retrieve-from`

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Instruction pair: protect-for / retrieve-from

$$\begin{array}{lll} \texttt{prot-for}\ v,\ dh & \text{encrypt}\ \{\!|\ v\ |\!\}_k & sh :=_{\text{caif}} ch(current) \\ \texttt{rtr-from}\ \{\!|\ v\ |\!\}_k,\ sh & \text{decrypt}\ v & dh :=_{\text{caif}} ch(current) \end{array}$$

- Device has a (purely local) intrinsic secret IS
- Keys derived via IS, current service and intended peer each identified by code hash $ch(svc)$

$$k \quad = \quad kdf(\texttt{"pf"},\ IS,\ sh,\ dh)$$

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Core questions

For a CAIF device d

Local to d: Can a service svc on d determine local service

1. src as source of data value v
2. dst as sole destination of data value v

Remote from d: Can principal not on d determine a service svc on d as the

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"Assured remote execution" by svc on d

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More challenging: Requires device-rooted protocol analysis
despite an adversary that can run programs

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Anchor for assured remote execution method

- Via shared secret key k_s
- Assumption 1: Each device has a distinct, publicly known
  - Immutable ID $imid$
- Assumption 2: We can once at factory?
  - Run a known anchor program anc on device
  - Deliver a shared secret r securely
  - Compute $k_s = kdf(\texttt{"c1"}, r, imid)$

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Run Anchor initially

At start in safe environment

- Run "anchor" program anc on device, that does:
  - Receive $\langle imid, sh, dh, r, n_0 \rangle$
  - Warn unless (i) $imid$ is mine, (ii) $sh = ch(anc)$
  - Let

$$k_s = kdf(\texttt{"c1"}, r, imid)$$

  - Execute `prot-for` k_s, dh
  - Send confirmation n_0
- Hence:

if any service svc gets k_s on device
then $dh = ch(svc)$

Mgt chooses one program to use k_s

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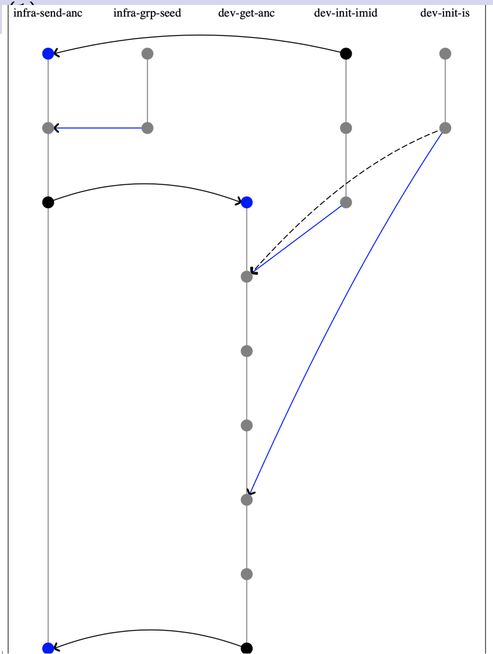
Where anchor key k_s goes to

Protocol analysis with CPSA shows (1)



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Mgt chooses one program to use k_s

- But: What should that program do with k_s?

Distributor program dtr

Use k_s to derive new per-service keys

- Distributor dtr, with $ch(dtr) = dtrh$, when run:
  - Retrieves k_s from anchor
  - Receives msg of form

$$\{\!|\, imid, (h, dtrh, ch(anc)), \ldots \,|\!\}_{k_s}$$

  - Sets $k_h = kdf(\texttt{"c2"}, k_s, h)$
  - Protects k_h for h
  - Exits, forgetting k_h
- For every svc:

  $k_{ch(svc)}$ is a shared secret between infrastructure with k_s and svc on device d

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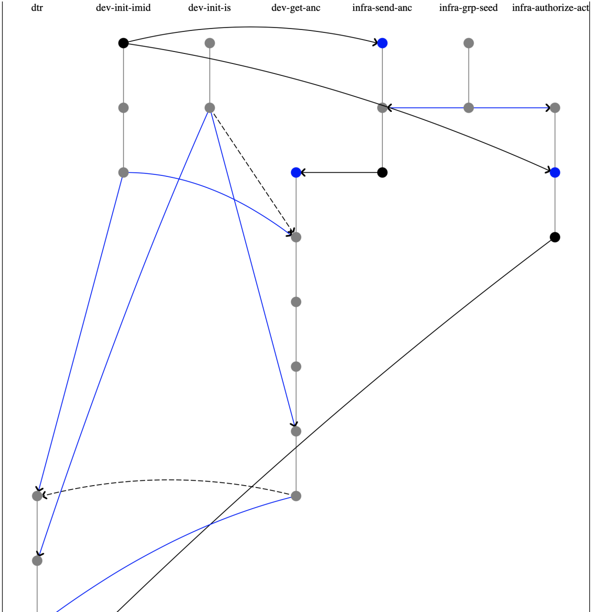
$(h, dtrh, ch(anc))$ is a trust chain

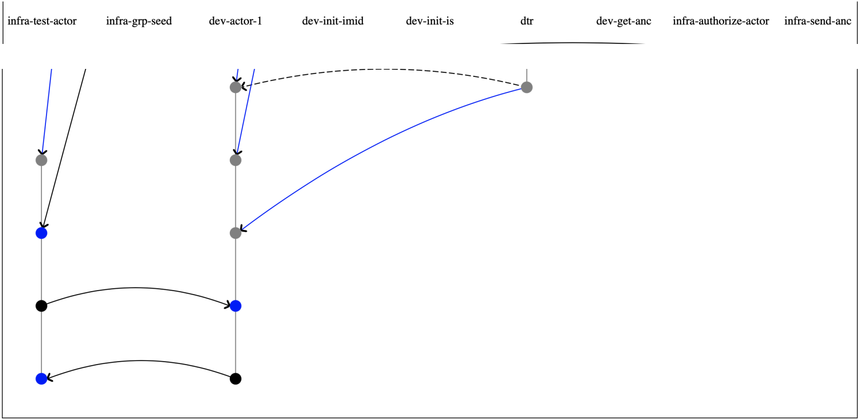
Where distributor command comes from

Protocol analysis with CPSA shows (2):



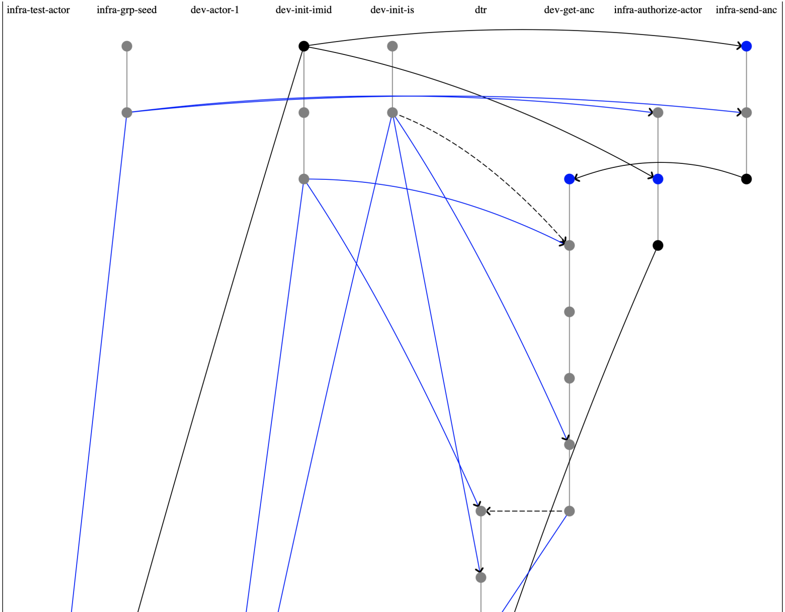
Testing an action keyed by distributor

Protocol analysis with CPSA shows (3):



Testing an action keyed by distributor (supplement)

Protocol analysis shows with CPSA (3):



Setting up trustworthy digital signatures

Distributor passes secret K_0 to service $SigGen$

- Setup phase:
  - Generate signature key pair (sk, vk) — Protect sk for myself
  - Prove possession of sk and K_0

$$\{\!|\ [\![\ldots,\quad ch(SigGen),\quad vk,\quad \ldots]\!]_{sk}\ |\!\}_{K_0}$$

  - Receive cert associating $ch(SigGen)$ and vk on $imid$

$$[\![\ldots,\quad imid,\quad ch(SigGen),\quad vk,\quad \ldots]\!]_{CA}$$

- Usage phase, for target service t:
  - Generate signature key pair tsk, tvk
  - Protect tsk for $ch(t)$ — Retrieve sk
  - Send cert associating $ch(t)$ and tvk on $imid$

$$[\![\ldots imid,\quad ch(t),\quad tvk\ldots]\!]_{sk}$$

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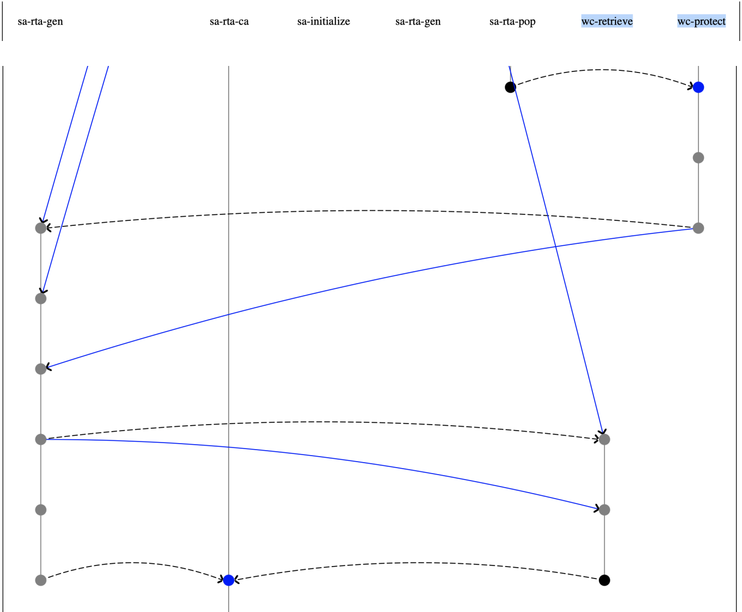
How to do this wrong

Against a powerful adversary that can run code on device



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$$[\![\ldots imid, \quad ch(t), \text{trust-ch}, \quad tvk \ldots]\!]_{sk}$$

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Adversary model, 1: Wildcat protect

```
(defrole wildcat-protect
    ...
    (trace
        (load lis (is-entry d is))
        (recv val)
        ...
        (stor loc (cat d (prot-for val (mem-key is srch dsth))))))
```

Wildcat-protect instances are subject to an axiom:

Axiom

If an instance of wildcat-protect uses a srch

Then, for that srch, not(compliant(srch))

Adversary model, 2: Wildcat retrieve

```
(defrole wildcat-retrieve
    ...
    (trace
        (load lis (is-entry d is))
        (load loc (cat d (prot-for val (mem-key is srch dsth))))
        (send val)))
```

Wildcat-retrieve instances are subject to an axiom:

Axiom

If *an instance of wildcat-retrieve uses a dsth*

Then, *for that dsth, not(compliant(dsth))*

Subliminal message

Security protocol analysis
can help solve problems
you may not think of as
security protocols

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Protocol analysis enables answers,
about devices facing a powerful adversary

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