Verified Boot in Chrome OS and how to make it work for you

Simon Glass
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Agenda

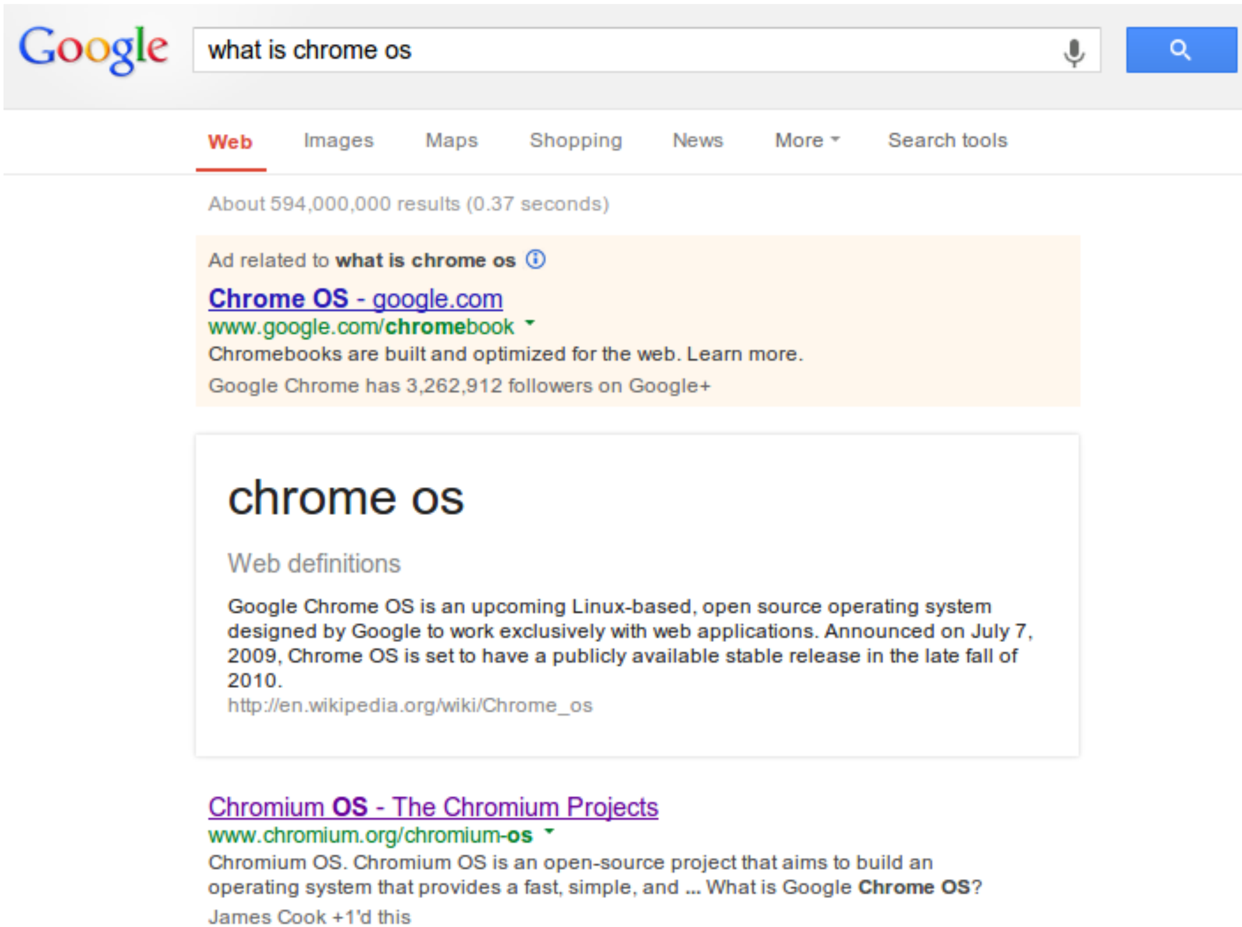
- Introduction
- Chrome OS
  - Verified Boot
- Requirements
- Technology
- U-Boot + Linux Verified Boot
- Demos
- Doing More
- Resources

Introduction

- Me
  - ARM technology since 1987
    - ARM in UK and US
    - Bluewater Systems (NZ ARM/Linux Electronics)
  - Google Chrome OS (first ARM laptop)

- Some professional Interests
  - Great ARM devices
  - Open Source Software

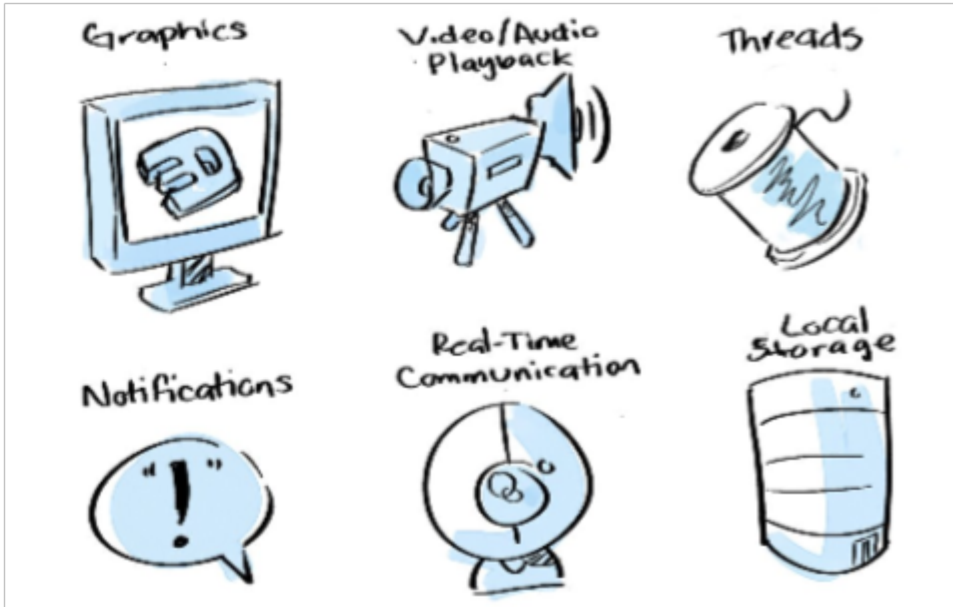
What is Chrome OS?



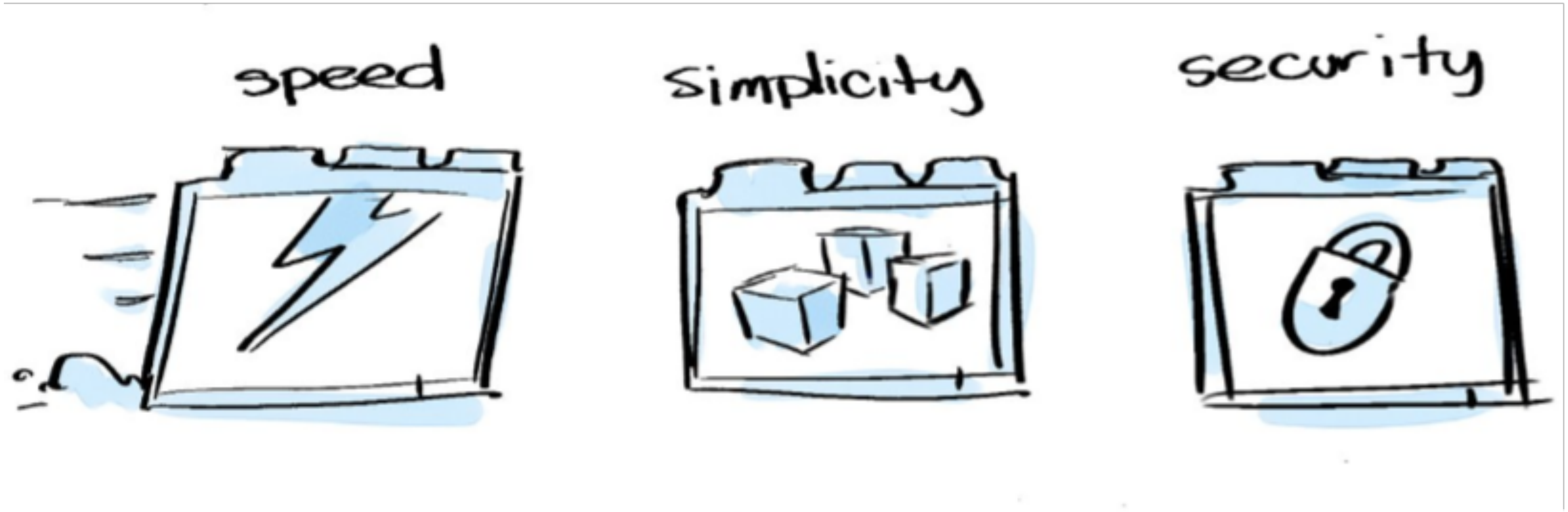
Converging forces

The migration to the cloud

The HTML 5 juggernaut

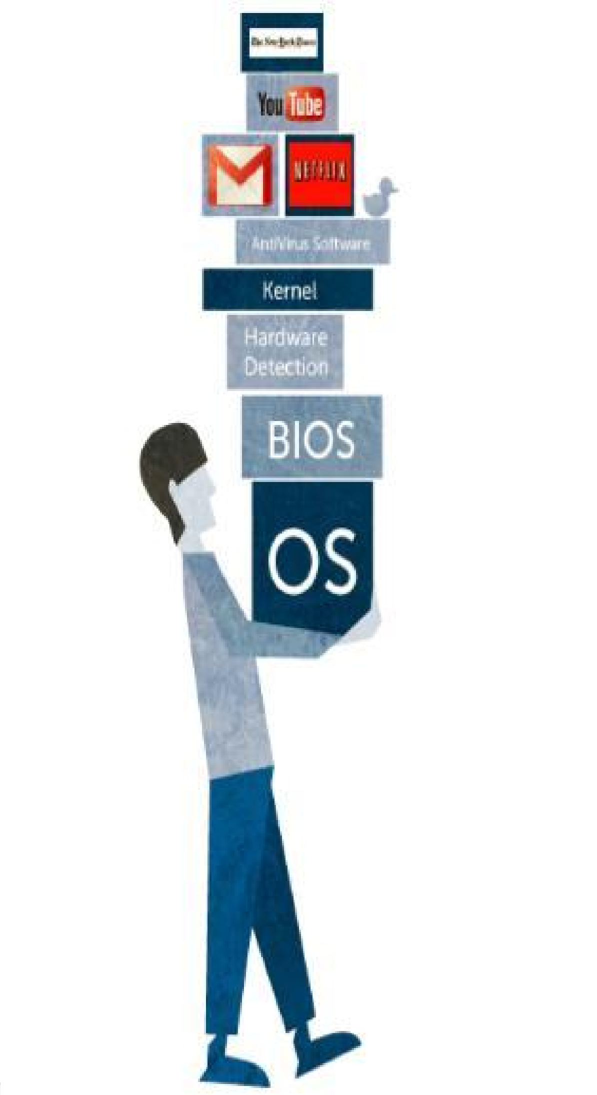


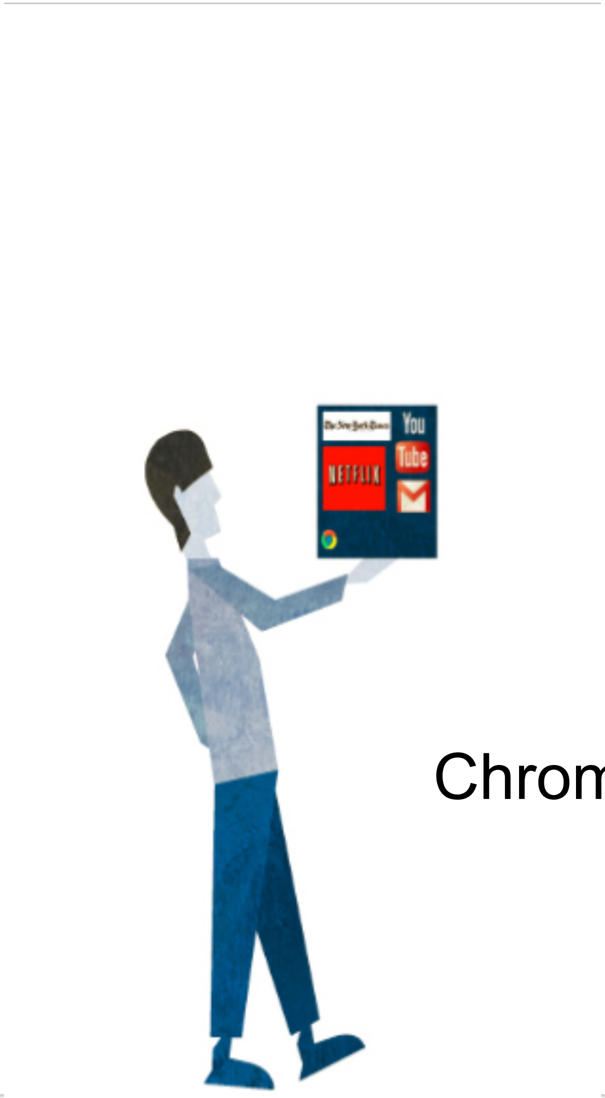
Chromebook



Integrated and streamlined

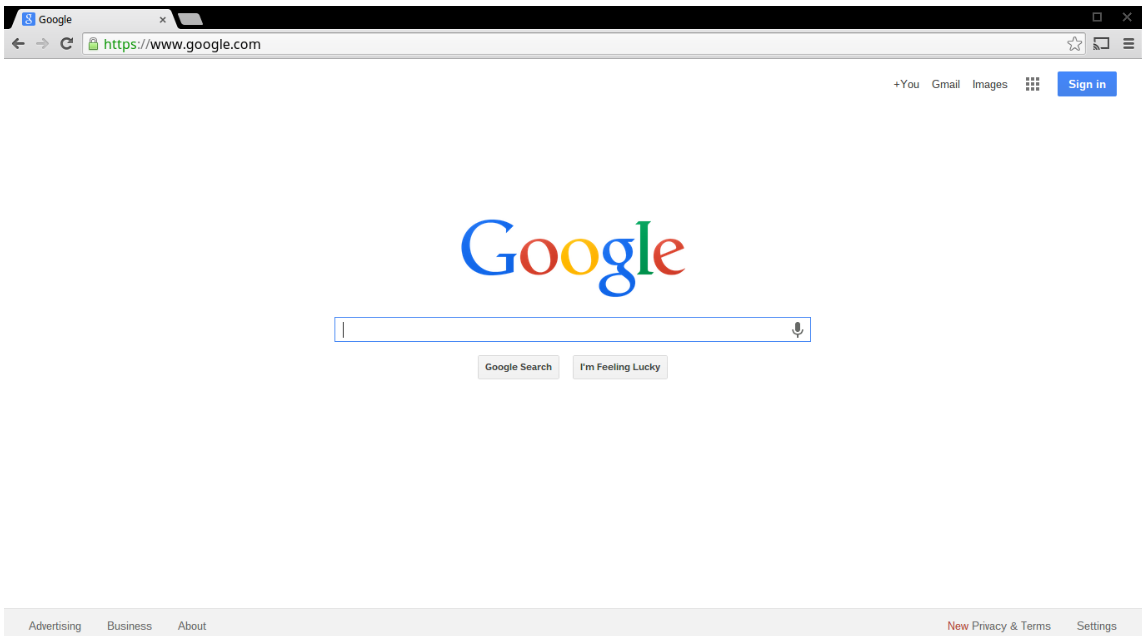
PC





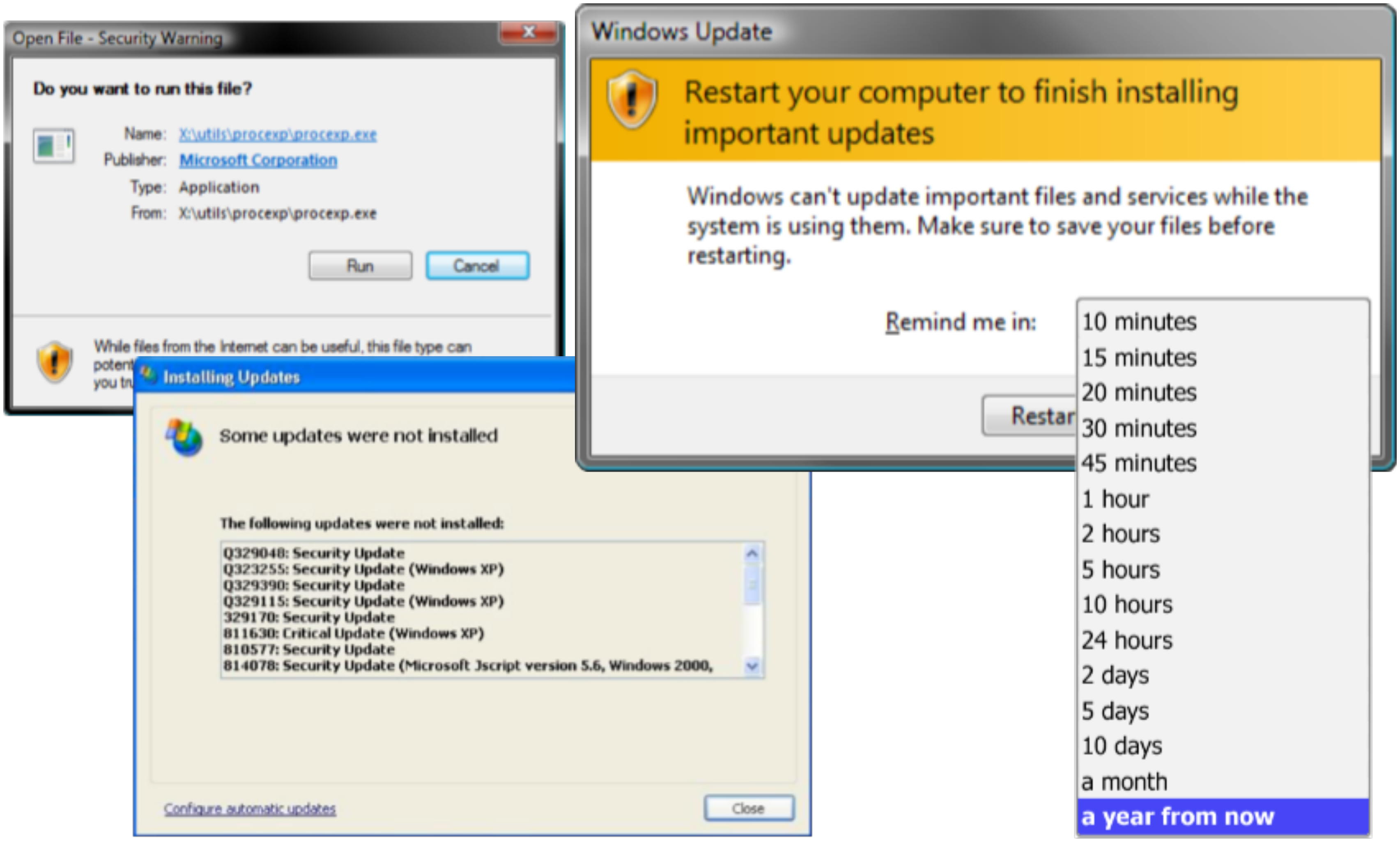
Chromebook

Simplicity



- Familiar UI
- Same experience everywhere
- Zero Maintenance
- Forever new
- "Rust" Proof
- Seamless sharing

Standard PC: Security as an afterthought



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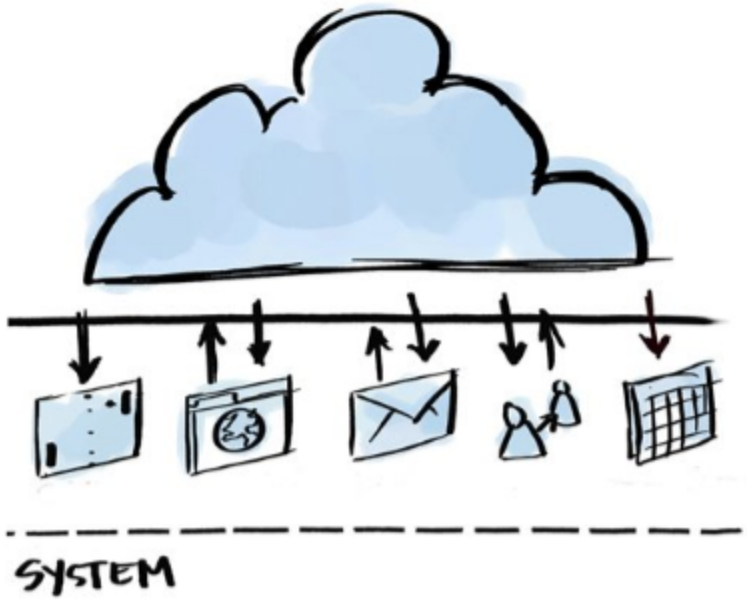
Security for the internet age

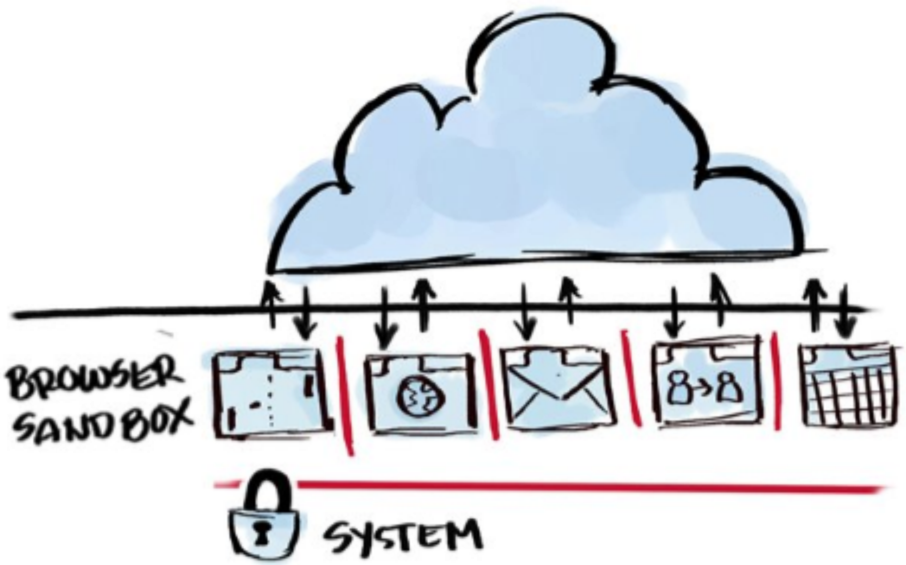
Current Operating Systems

- Apps have the same privileges and power as you



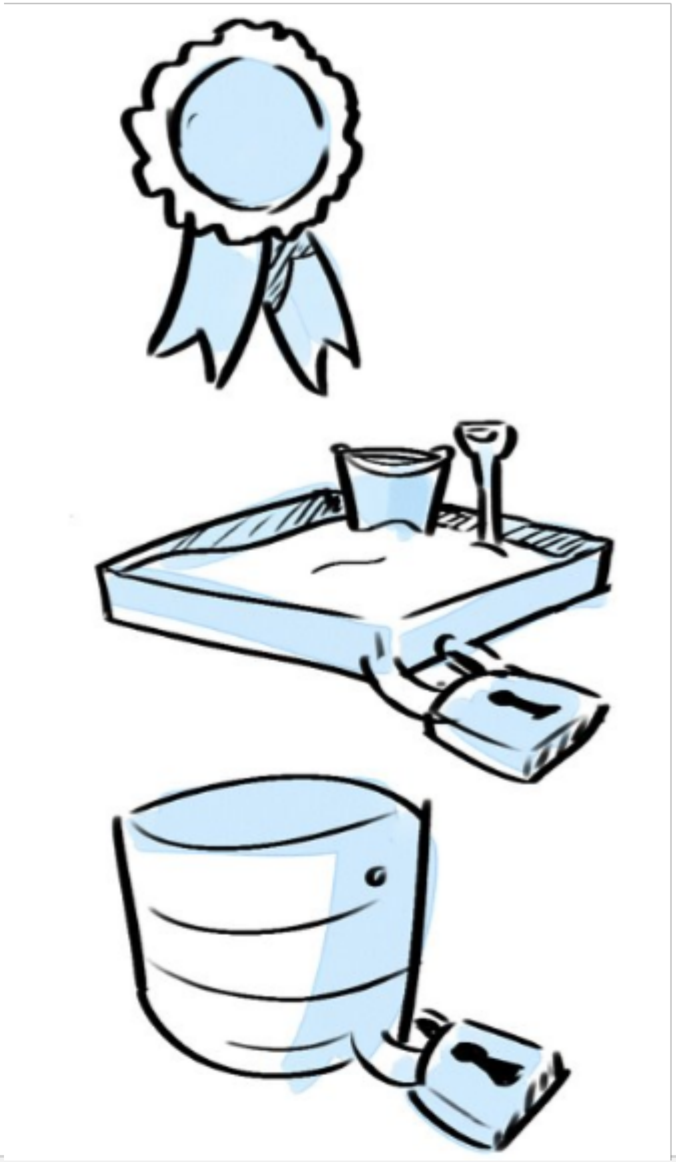
Chrome OS

- Web apps and offline apps
- The OS doesn't trust any of them
- Keep them isolated and sandboxed



Chrome OS' defense in depth

- Small list of known executables
  - Signed and verified before each use
- Run in secured sandboxes
  - Chroot, Namespaces
  - Toolchain, Stack protection
- File system is locked down
  - Read-only root file system
  - User data encryption
- Automatic updates for the entire OS
  - Nothing is ever perfect.
  - It's not the user's job to keep it secure.



Google

Why Verified Boot?

- Reduced risk of malware
- Keeps users safe
- Permits safe software updates in the field
- Known software on device

- Verified Boot does not mean the user needs to be locked out
    - E.g. See Chrome OS ‘dev mode’

Requirements of Verified Boot

- Root of trust (static in our case)
- Every byte of code/data loaded is verified
  - Can use a sandbox where this is impractical
- Prior state must be fully validated
- Security holes plugged
- Upgradeable software
- Rollback protection

Technology

- Hashing
- Public key cryptography
- Trusted Platform Module (TPM)
- Root of trust

Hashing of binary images

- Reducing an image down to a very small data block ('digest')
- Two images can be considered:
  - Identical if their digests are the same
  - Different if their digests differ
- For a good hashing algorithm:
  - Changing just one bit in the image should completely change the digest
  - 'Collision resistant' - need to try sqrt(2^n) images
  - Infeasible to modify an image to obtain a certain digest
- Common hashing algorithms are:
  - SHA1 - 24 byte digest
  - SHA256 - 32 byte digest

Public key cryptography

- Create a key pair to sign a hash, and later to verify its signature
  - One key is ‘private’ – used to sign images and kept secret
  - Other key is ‘public’ – widely broadcast without affecting security
- Two keys are mathematically related
  - Data encrypted by one can be decrypted by the other
- With the public key we can verify that a hash was signed by the associated private key
- Common public key algorithms are RSA and ECC
  - RSA 2048 bits is considered strong

Trusted Platform Module (TPM)

- Security chip
  - Each device has a unique RSA private key
  - Can store keys, roll-back counters
  - Random number and key generation
- Commonly used on high-end laptops, or with a plug-in PCB
  - Typically I2C or LPC bus
  - Many ARM devices make use of TrustZone instead of a discrete TPM
  - Requires additional software
- TPM can check software and configuration at start-up
  - Hash each new chunk before using it
  - Pass the hash to the TPM for checking

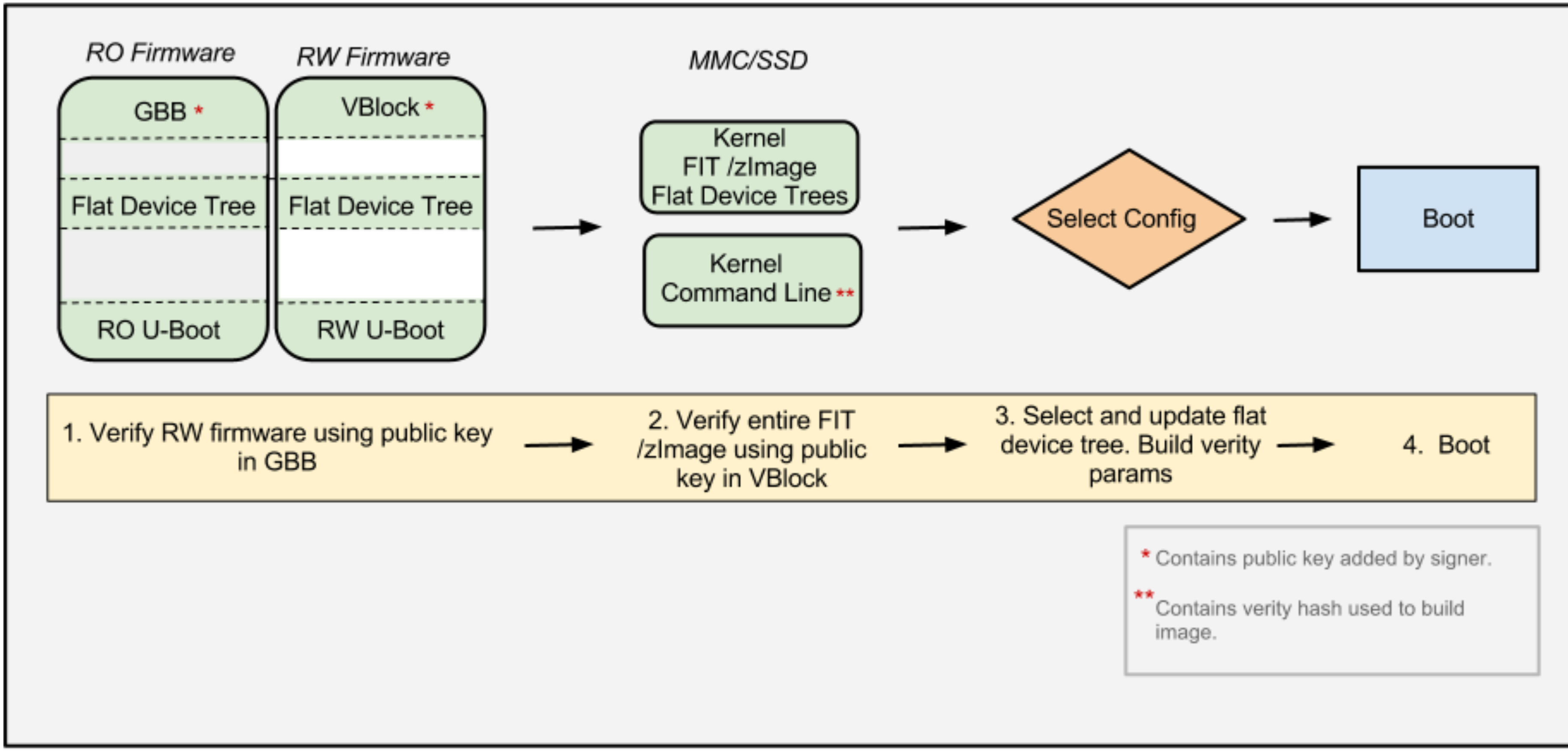
Root of trust

- Simple ‘static root of trust’
  - Initial code is assumed to be trusted
  - Boot ROM, U-Boot
- Can be stored in read-only memory
  - Or signed so that SoC can verify it
- Root stage holds keys for checking later stages
- From there we can load each stage of boot
  - Verify each as we go, using keys provided by the previous stage

Verified boot in Chrome OS

- ‘Verified boot’ is the term used in Chrome OS
- Firmware
  - U-Boot and verified boot library (also Coreboot on x86)
- Kernel
  - dm-verity
  - A few drivers
- User space
  - Firmware interface, update
  - Chrome OS update
- Other
  - Signer
  - Other utilities

Verified boot flow - firmware



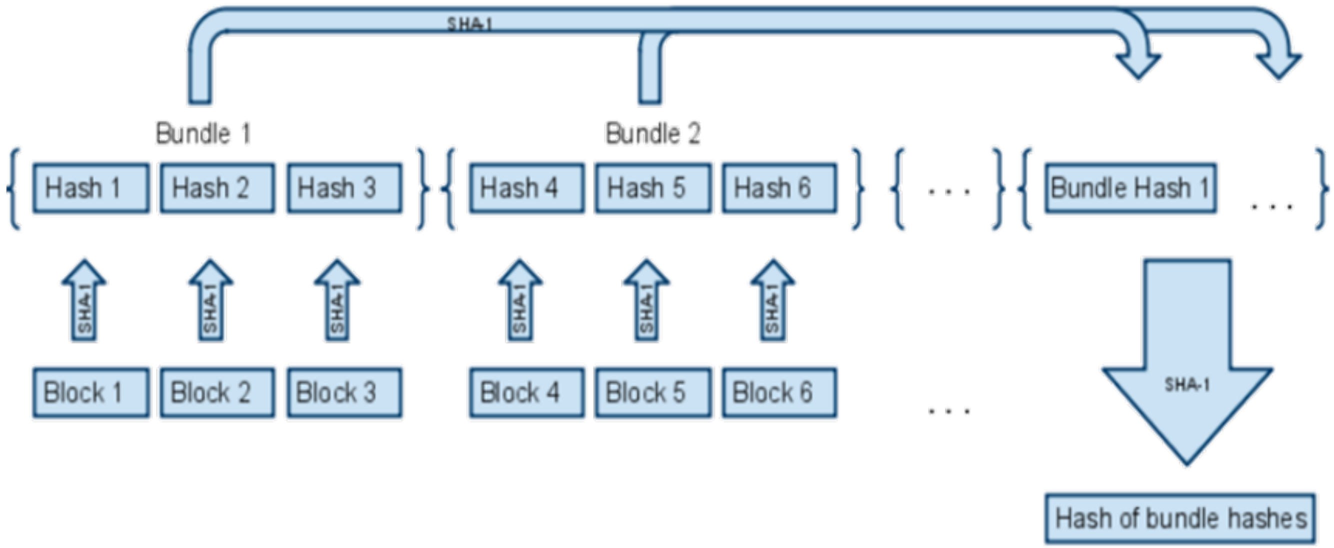
- Firmware, kernel and root disk all have an A and a B

Verified boot components - firmware

- U-Boot 2013.06
  - Main source base
  - Drivers and subsystems
  - Vboot integration layer in cros/ subdirectory
  - Full source code here http://goo.gl/N6rhik
- Vboot library
  - Hashing
  - RSA / signature checking
  - Verified boot ‘logic flow’
  - TPM library (only used for roll-back counters)
  - Full source code here http://goo.gl/dTbkLs

Verified Boot Components - Kernel

- dm-verity merged to Linux in 2012



- cryptohome (not really verified boot)
  - http://www.chromium.org/chromium-os/chromiumos-design-docs/protecting-cached-user-data

Verified Boot Components - User space

- crossystem
  - Allows access to firmware settings
  - Allows signals to be sent to firmware for next boot
- update_engine
  - Update the partition we did not boot
- chromeos_firmwareupdate
  - Update the firmware we did not boot

- Also a few tools
  - Signer
  - cros_bundle_firmware
  - Image utilities

Chromium OS is Open Source

http://git.chromium.org/gitweb/

chromium-review.googlesource.com

DIY Verified Boot

- Can I implement verified boot on my own platform?
    - Yes
- Do I need UEFI?
    - No

- U-Boot
    - Use FIT if you don’t already
    - Imager signer is the trusty mkimage
    - Continue to use bootm
    - Will go through this in some detail
- Linux
    - dm-verity is upstream
- Firmware<->user space layer
    - Roll your own

Introduction to FIT

```
/ {
	description = "Simple kernel / FDT configuration (.its file)";

	images {
		kernel@1 {
			data = /incbin/("../vmlinuz-3.8.0");
			kernel-version = <1>;
			hash@1 {
				algo = "sha1";
			};
		};
		fdt@1 {
			description = "snow";
			data = /incbin/("exynos5250-snow.dtb");
			type = "flat_dt";
			arch = "arm";
		};
	};
	configurations {
		default = "conf@1";
		conf@1 {
			kernel = "kernel@1";
			fdt = "fdt@1";
		};
	};
};
```

http://goo.gl/a09ymG

Adding a signature to a FIT

```
/ {
	description = "Simple kernel / FDT configuration";

	images {
		kernel@1 {
			data = /incbin/("../vmlinuz-3.8.0");
			kernel-version = <1>;
			signature@1 {
				algo = "sha1,rsa2048";
				key-name-hint = "dev";
			};
		};
		fdt@1 {
			description = "snow";
			data = /incbin/("exynos5250-snow.dtb");
			type = "flat_dt";
			arch = "arm";
		};
	};
	configurations {
		default = "conf@1";
		conf@1 {
			kernel = "kernel@1";
			fdt = "fdt@1";
		};
	};
};
```

Use bootm as normal

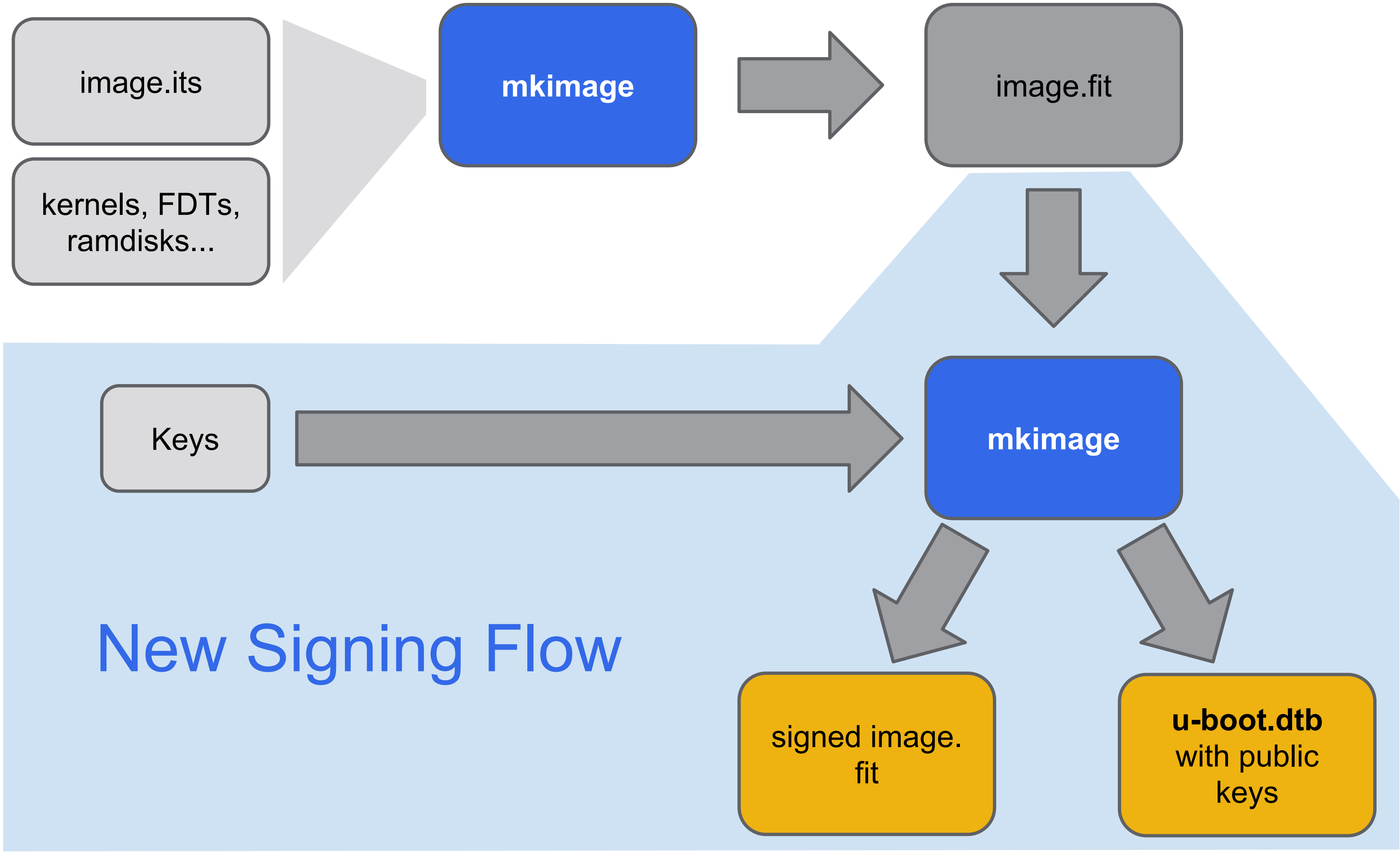
```
## Loading kernel from FIT Image at 00000100 ...
   Using 'conf@1' configuration
   Trying 'kernel@1' kernel subimage
     Description:  unavailable
     Type:         Kernel Image (no loading done)
     Compression:  uncompressed
     Data Start:   0x000001c8
     Data Size:    5000 Bytes = 4.9 KiB
   Verifying Hash Integrity ... sha1,rsa2048:dev+ OK
## Loading fdt from FIT Image at 00000100 ...
   Using 'conf@1' configuration
   Trying 'fdt@1' fdt subimage
     Description:  snow
     Type:         Flat Device Tree
     Compression:  uncompressed
     Data Start:   0x0000164c
     Data Size:    4245 Bytes = 4.1 KiB
     Architecture: Sandbox
   Verifying Hash Integrity ... sha1,rsa2048:dev+ OK
   Booting using the fdt blob at 0x00164c
   XIP Kernel Image (no loading done) ... OK
. . .
```

Signing images using mkimage

mkimage -f test.its -k ../keys -K out/u-boot.dtb -r test.fit

- -k Key directory
- -K Output FDT for public keys
- -r Require verification of all keys

How signing works



Signed image.fit

```
images {
    kernel@1 {
        data = <3.4MB of stuff>;
        signature@1 {
            algo = "sha1,rsa2048";
            key-name-hint = "dev";
            timestamp = <0x50e4b667>;
            signer-version = "2013.01";
            signer-name = "mkimage";
            value = <0x32e48cf4 0xa72b7504 0xe805aeff 0xe1afb2e8 0x24c5313f
                0xb4b3d41b 0x3cf03e60 0x309553a2 0xc1a0a557 0x3e103a1c ...
                0xc293395e 0x06cfa9e5 0x1cda41e1 0xb0a10e97 0xa92d8d61>;
        };
    };
    fdt@1 {
        description = "snow";
        data = <12KB of stuff>;
        signature@1 {
            algo = "sha1,rsa2048";
            key-name-hint = "dev";
            timestamp = <0x50e4b667>;
            signer-version = "2013.01";
            signer-name = "mkimage";
            value = <0x32e48cf4 0xa72b7504 0xe805aeff 0xe1afb2e8 0x24c5313f
                0xb4b3d41b 0x3cf03e60 0x309553a2 0xc1a0a557 0x3e103a1c ...
                0xc293395e 0x06cfa9e5 0x1cda41e1 0xb0a10e97 0xa92d8d61>;
    };
};
```

u-boot.dtb with public keys

```
/ {
    model = "Google Link";
    compatible = "google,link", "intel,celeron-ivybridge";
    signature {
        key-dev {
            algo = "sha1,rsa2048";
            required;
            rsa,r-squared = <0x0a1ed909 0xf564a4e6 0x539e6791 0x9d9b4a7e 0x2a7788cf
0x89f9cb7a 0x7cd7a2c3 0xdb02b925 0x97f6cd15 0x76c86fb0 0x16b7b120 0x5825dc2c ...
0x0e9e736a 0x852372bd 0x13a08e33>;
            rsa,modulus = <0xc1ad79b6 0x52ef561b 0x2c8b2a54 0x13436fa4 0xcabce1b9
0x64c6e1c8 0xbfebf9a2 0x1e3d974c 0x14a67ada 0x4ecc3648 0xa7fee936 0xb53cc0a8 ...
0xabe4f37f 0xdcc15a79 0xfcd530a5>;
            rsa,n0-inverse = <0x75a89dbf>;
            rsa,num-bits = <0x00000800>;
            key-name-hint = "dev";
        };
    };
...
```

In-place signing

- FIT is a very flexible format
- No need to write the signature to a separate place/file
  - Just update the FIT
  - Multiple signatures can be added later without affecting previous signing
- Hashing algorithm supports hashing portions of the FIT

Signing configurations

```
/ {
        images {
                kernel@1 {
                        data = /incbin/("test-kernel.bin");
                        type = "kernel_noload";
                        hash@1 {
                                algo = "sha1";
                        };
                };
                fdt@1 {
                        description = "snow";
                        data = /incbin/("sandbox-kernel.dtb");
                        hash@1 {
                                algo = "sha1";
                        };
                };
        };
        configurations {
                conf@1 {
                        kernel = "kernel@1";
                        fdt = "fdt@1";
                        signature@1 {
                                algo = "sha1,rsa2048";
                                key-name-hint = "dev";
                                sign-images = "fdt", "kernel";
                        };
                };
        };
};
```

Nodes to hash:

/
/configurations/conf@1
/images/kernel@1
/images/kernel@1/hash@1
/images/fdt@1
/images/fdt@1/hash@1

Using bootm with configuration signing

```
## Loading kernel from FIT Image at 00000100 ...
   Using 'conf@1' configuration
   Verifying Hash Integrity ... sha1,rsa2048:dev+ OK
   Trying 'kernel@1' kernel subimage
     Description:  unavailable
     Type:         Kernel Image (no loading done)
     Compression:  uncompressed
     Data Start:   0x000001c8
     Data Size:    5000 Bytes = 4.9 KiB
   Verifying Hash Integrity ... sha1+ OK
## Loading fdt from FIT Image at 00000100 ...
   Using 'conf@1' configuration
   Trying 'fdt@1' fdt subimage
     Description:  snow
     Type:         Flat Device Tree
     Compression:  uncompressed
     Data Start:   0x0000164c
     Data Size:    4245 Bytes = 4.1 KiB
     Architecture: Sandbox
   Verifying Hash Integrity ... sha1+ OK
   Booting using the fdt blob at 0x00164c
   XIP Kernel Image (no loading done) ... OK
```

U-Boot code size

- OpenSSL is only used in mkimage
  - Produces pre-processed public key parameters for U-Boot run-time
  - Modulus (n), r-squared, n0-inverse and num-bits
- U-Boot simply has to do exponential mod n
- Code size is very efficient
  - RSA verification code is only 2149 bytes (Thumb 2)
- Entire RSA FIT code adds 6.2KB code/data
  - If you don’t already use FIT, then that adds an additional 20KB
  - Both FIT and RSA add only ~12.5KB to gzip-compressed U-Boot size

```
$ ./tools/buildman/buildman -b talk snow  -Ss
Summary of 3 commits for 1 boards (1 thread, 32 jobs per thread)
01: Merge branch 'master' of git://git.denx.de/u-boot-mmc
02: enable fit
       arm: (for 1/1 boards)  all +20437.0  bss +60.0  data +504.0  rodata +1953.0  text +17920.0
03: Enable verified boot
       arm: (for 1/1 boards)  all +6337.0  bss -40.0  data +16.0  rodata +697.0  text +5664.0
```

U-Boot performance

- Time to check FIT configuration with 2048-bit RSA signature
  - <6ms on Beaglebone (1GHz Cortex-A8)
  - Note: if you care about performance, turn on the cache
    - With cache off it is 290ms

Nice Properties of U-Boot's verified boot

- Small 6.2KB code on Thumb 2
- Faster - 6ms on 1GHz Cortex-A8
- Uses existing FIT format
  - No need for multiple files - data and signatures are in the FIT
- Can sign and re-sign existing images
  - Signing uses the existing mkimage tool
- No new boot flow - works with existing scripts that use bootm
- Supports multiple stages, sub-keys, etc.

Using bootm

- Verified boot still uses bootm
  - No change in syntax
- Signature verification plumbed into existing image-checking code
- Image check just sits along existing hash/CRC checking
- Configuration check happens before this
  - As soon as the configuration is selected

Demo time

Doing more

- Accelerated hashing
  - U-Boot and Linux have a framework
- Auto-update
- Recovery mode
- Other root of trust options
- Performance
- TPM for roll-back
- Trusted boot using TPM extend

Conclusion

- Verified boot can be enabled in most embedded systems
  - Main new requirement is a verified root of trust
- Available in mainline U-Boot
  - Adds just 6.2KB code and a small run-time penalty
- U-Boot TPM library provides roll-back protection
  - 'Extend' functionality also available if desired
- Read-only root filesystem can be protected with dm-verity
  - Chrome OS uses this approach

Google

Thank you

- U-Boot verified boot
  - http://git.denx.de/cgi-bin/gitweb.cgi?p=u-boot.git;a=blob;f=doc/uImage.FIT/verified-boot.txt
- dm-verity
  - https://lwn.net/Articles/459420/
  - https://code.google.com/p/cryptsetup/wiki/DMVerity
- Chrome OS
  - http://www.chromium.org/chromium-os/chromiumos-design-docs
- Other ideas:
  - http://selinuxproject.org/~jmorris/lss2013_slides/safford_embedded_lss_slides.pdf
  - https://github.com/theopolis/sboot
- Email me sjg@chromium.org
  - cc u-boot@lists.denx.de

Additional slides

U-Boot's TPM Support

- TPM library
  - tpm_startup()
  - tpm_self_test_full()
  - tpm_nv_define_space()
    - tpm_nv_read_value()
    - tpm_nv_write_value()
  - tpm_extend()
  - tpm_oiap()...
- Drivers for common TPMs
  - Infineon (I2C and LPC), Atmel, STM
- 'tpm' command
  - Provides full access to TPM library for scripts