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Extending Integrity Measurement Architecture for Attestation

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Contents

Problem Statement:
Boot Sequence of Cloud Native Workloads

BIOS: Static Root of Trust
-> GRUB: Static Root of Trust
-> tboot (trusted boot): load tdx-module, build time measurement register (MRTD)
-> kernel: Dynamic Root of Trust
-> initrd: full disk encryption
-> init (including ACPI subsystem)
-> daemons
-> cloud native daemons
-> containers
-> sidecars and applications
-> handles workloads and requests

Problem Statement:
Attestation for TEE – TDX 1.0

Architecture Support

```
// #define TDX_GET_INFO          1 // TDCALL for Guest prepare
// #define TDX_GET_REPORT        4  // TDCALL, in Guest get integrity measure
#define TDG_VP_VMCALL                    0
#define TDG_VP_INFO                      1
#define TDG_MR_REPORT                    4
#define TDVMCALL_GET_QUOTE               0x10002
```

Table 2.9: Guest-Side (TDCALL Leaf) Interface Functions

Interface Function Name	Leaf Number	Description
TDG.MEM.PAGE.ACCEPT	6	Accept a pending private page into the TD
TDG.MR.REPORT	4	Creates a cryptographic report of the TD
TDG.MR.RTMR.EXTEND	2	Extend a TD run-time measurement register.
TDG.VP.CPUIDVE.SET	5	Control delivery of #VE on CPUID instruction execution
TDG.VP.INFO	1	Get TD execution environment information
TDG.VM.RD	7	Read a TD-scope metadata field
TDG.VM.WR	8	Write a TD-scope metadata field
TDG.VP.VEINFO.GET	3	Get Virtualization Exception Information for the recent #VE exception
TDG.VP.VMCALL	0	Call a host VM service

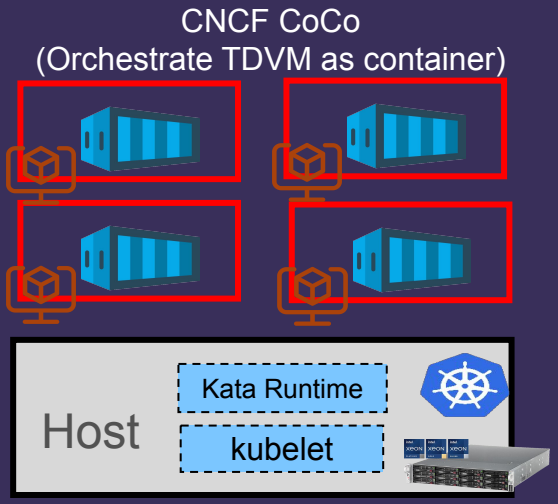
Kernel Support

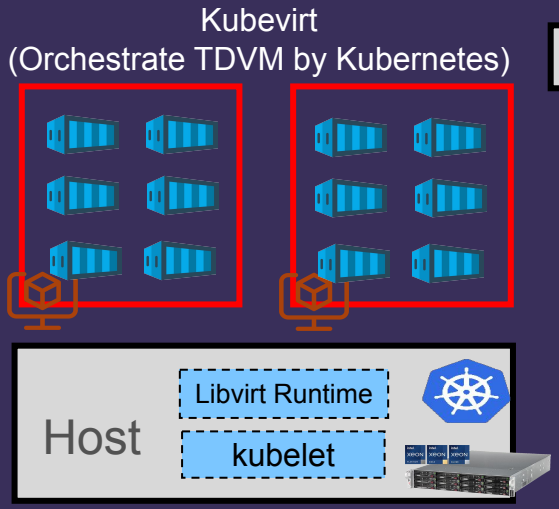
```
// u64 __tdx_module_call(u64 fn, u64 rcx, u64 rdx, u64 r8, u64 r9, struct tdx_module_output *out); // TDCALL 5.15
u64 __tdcall(u64 fn, struct tdx_module_args *args); // upstream
u64 __tdx_hypercall(struct tdx_module_args *args); // upstream

/* ./arch/x86/coco/tdx/tdx.c */
int tdx_mcall_get_report0(u8 *reportdata, u8 *tdreport); // through module call, TDCALL
int tdx_hcall_get_quote(void *tdquote, int size); // through hypercall, TDCALL
```

Problem Statement:

Limitations in Cloud Native Scenarios





Bare Metal

Confidential VM

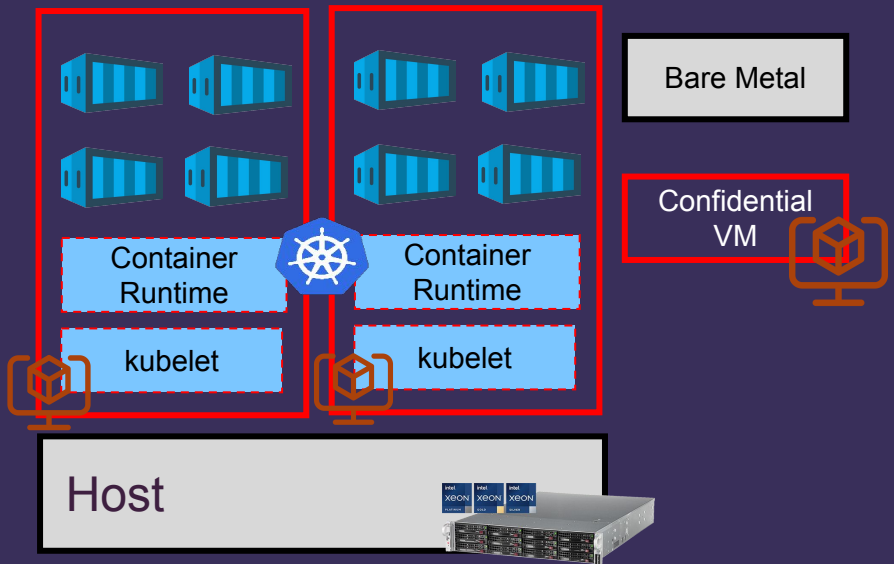
Only Supports per Secure Container level or VM level Attestation

- I/O Bottleneck
- Unable to scale up, no HPA supported (unable to snapshot)
- Unable to scale out in large scale

Goal:

Attestation for Cloud Native Deployment

Confidential Cluster (Deploy K8S cluster in TDVM)



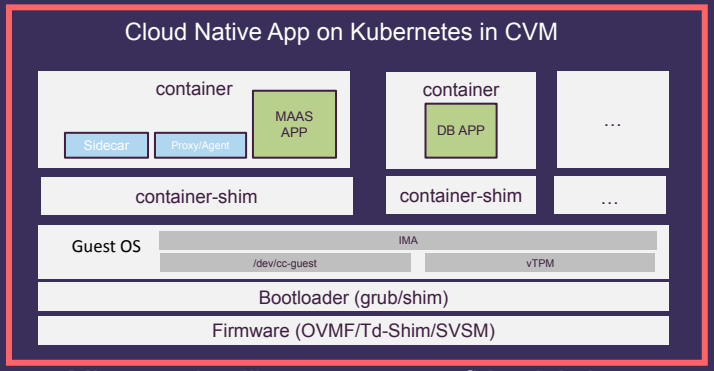
- Supports several containers in one CVM, no I/O Bottleneck between containers in one CVM
- Supports attested cluster of containers
- Supports Dynamic Resource Allocation (DRA)
  - scale up (HPA) through snapshot
  - scale out (batching) through warm pool and ps-tree fork

Goal:

Attestation for Cloud Native Deployment

Confidential **Database** Service and Confidential **Model-as-a-Service** deployments commonly encompass multiple containers distributed across several virtual machines (VMs).

M (workload) = M (vm/secure container) ||
M (trusted domain) ||
M (trusted container launcher) ||
M (application)
\



Microservice-like app on a confidential cluster

This deployment model necessitate attestation for userspace code:

- **container launch time** integrity measurement and attestation
- **application initialization time** integrity measurement and attestation
- attestation for **Trusted Computing Base(TCB)** only

Key Idea:

Extending IMA for Workload Attestation

→ CC Trusted API & CCNP

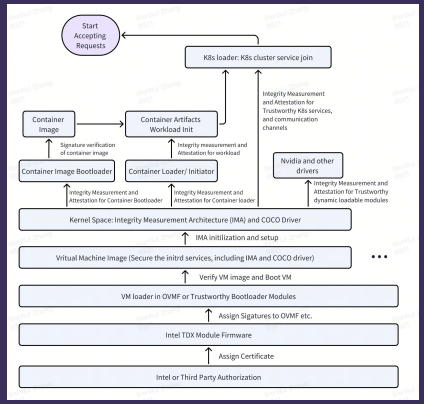
- RTMR Backend
- Digest list
- Trusted Domain
- Trusted Container Launcher

Extending Integrity Measurement Architecture for Workload Attestation

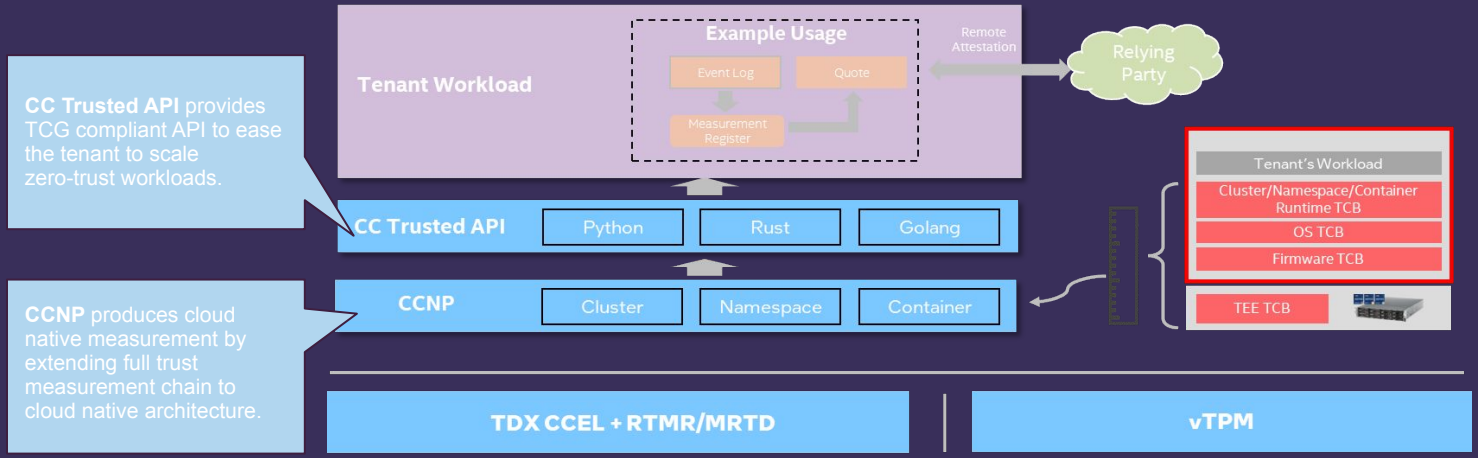
M (workload) = M (vm/secure container) ||**M (trusted domain)** || **M (trusted container launcher)** || M (application)

This work focuses on enabling measurement for:

- trusted domain (e.g., nvidia.ko, k8s daemons, container runtimes, ccnp toolkit, trusted launcher etc..),



Overview:
CC Trusted API & CCNP



CC Truste API: https://github.com/cc-api/cc-trusted-api
CCNP: https://github.com/cc-api/confidential-cloud-native-primitives

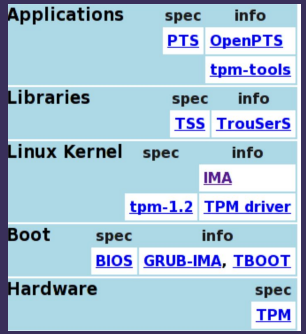
Background:
Integrity Measurement Architecture

- Measure all files before they are used according to the measurement policy
- Store measurements in kernel list, a.k.a., IMA measurement list
- Extend measurements into **TPM/vTPM** PCR. configurable, 10 for application
- TPM signed attestation report of measurement list, through TPM_QUOTE

IMA Raw output

```
10 1609097048173d7c1659ff33713741b98020d0d8 ima a36e075c9dc23bd71886d55e0daee556143f8e7e boot_aggregate
10 3d82394c528268a62687c8b59b34c39137b4fb3c ima ff65625e34131617ef3ac5fead5cb285b6aa73b9 /init
10 231309f206f12296cff6c59c6e3bceb45dc285bb ima 602acdac8864b113d4546bf8f2d7b96c81607792 /init
10 9d20d222ae9a3a9c80b2a9f0b3c08a5786847ed6 ima ff4c31959c04f865c859d8df331a6bf6b6967cef ld-2.10.1.so
10 88a2bee776f4bd1305ce6ded08611fdecb5bf0db ima 44e727b6c99370d373d0acef95631e0950ef8c00 ld.so.cache
10 0c86c858b30abf3f2c3b0269a56204f642f3ef71 ima a0ed012c34fee03e9fecee8d4a7bcab1ff98f091 libnash.so.6.0.87
10 676a27e4112c9fb5677b7ef38cc488d87fca0846 ima bf094171a04b06d642c931d7c2ce0a707a659827 libbdevid.so.6.0.87
10 04c918d9ccb56ca92a118b72f8b2f60da0791887 ima 9355215ed19d72287c446d0f3b7b41dcaddbd254 libdevmapper.so.1.02
10 6585544486aee180aa950b1bb6132434cf0f71d6 ima caca8bbf8ff4957584d114c753b7c4f15936af7c libparted-1.8.so.8.0.0
```

After typical boot (Fedora 11), 1600 measurements.
Overhead at boot time, 10% (3-5 seconds).
Slight performance improvement at runtime (a lot prefetched).



Pictures credited to David Safford, Mimi Zohar, Reiner Sailer, https://blog.linuxplumbersconf.org/2009/slides/David-Stafford-IMA_LPC.pdf

Background:
Integrity Measurement Architecture

```
#define __ima_hooks(hook)                                   \
        hook(NONE, none)                                    \
        hook(FILE_CHECK, file)                              \
        hook(MMAP_CHECK, mmap)                              \
        hook(MMAP_CHECK_REQPROT, mmap_reqprot)              \
        hook(BPRM_CHECK, bprm)                              \
        hook(CREDS_CHECK, creds)                            \
        hook(POST_SETATTR, post_setattr)                    \
        hook(MODULE_CHECK, module)                          \
        hook(FIRMWARE_CHECK, firmware)                      \
        hook(KEXEC_KERNEL_CHECK, kexec_kernel)              \
        hook(KEXEC_INITRAMFS_CHECK, kexec_initramfs)        \
        hook(POLICY_CHECK, policy)                          \
        hook(KEXEC_CMDLINE, kexec_cmdline)                  \
        hook(KEY_CHECK, key)                                \
        hook(CRITICAL_DATA, critical_data)                  \
        hook(SETXATTR_CHECK, setxattr_check)                \
        hook(MAX_CHECK, none)
```

```
static const char *const
mask_tokens[] = {
        "^MAY_EXEC",
        "^MAY_WRITE",
        "^MAY_READ",
        "^MAY_APPEND"
  };
```

Source: https://elixir.bootlin.com/linux/v6.8-rc7/source/security/integrity/ima/ima.h

Contribution 1:
RTMR Backend

Architecture Support

u64 __tdx_module_call(u64 fn, u64 rcx, u64 rdx, u64 r8, u64 r9, struct tdx_module_output *out); // TDCALL

```
#define TDX_GET_INFO          1 // TDCALL for Guest prepare
#define TDX_EXTEND_RTMR       2  // TDCALL , in Guest invoke integrity measure
#define TDX_GET_REPORT        4  // TDCALL, in Guest get integrity measure
#define TDX_VERIFYREPORT      22 // TDCALL 1.5 only, in Guest-driver attestation
```

Table 2.9: Guest-Side (TDCALL Leaf) Interface Functions

Interface Function Name	Leaf Number	Description
TDG.MEM.PAGE.ACCEPT	6	Accept a pending private page into the TD
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TDG.MR.RTMR.EXTEND	2	Extend a TD run-time measurement register
TDG.VP.CPUIDVE.SET	5	Control delivery of #VE on CPUID instruction execution
TDG.VP.INFO	1	Get TD execution environment information
TDG.VM.RD	7	Read a TD-scope metadata field
TDG.VM.WR	8	Write a TD-scope metadata field
TDG.VP.VEINFO.GET	3	Get Virtualization Exception Information for the recent #VE exception
TDG.VP.VMCALL	0	Call a host VM service

Kernel and TDX Module Support

/* ./arch/x86/coco/tdx/tdx.c */

```
int tdx_mcall_extend_rtmr(u8 *data, u8 index);
int tdx_mcall_get_report0(u8 *reportdata, u8 *tdreport);
u64 tdx_mcall_verify_report(u8 *reportmac);
int tdx_hcall_get_quote(void *tdquote, int size);
```

Contribution 1:
RTMR Backend

Kernel Support to vTPM Driver

```
/* ./arch/x86/include/asm/tdx-rtmr.h */
struct tpm_chip *tdx_rtmr_device(void); // a fake TPM device for IMA usage,TPM_ALG_SHA384
int ima_extend_rtmr(struct tpm_chip *chip, u32 rtmr_idx, struct tpm_digest *digests);
int tdx_get_boot_measurements(struct tdx_boot_digests *boot_digests);
/* ./arch/x86/include/asm/tdx.h */
void ccel_record_eventlog(void *data, u8 index);
```

Contribution 1:
RTMR Backend

Kernel Support to vTPM Driver

```
/* ./arch/x86/include/asm/tdx-rtmr.h */
struct tpm_chip *tdx_rtmr_device(void); // a fake TPM device for IMA usage,TPM_ALG_SHA384
int ima_extend_rtmr(struct tpm_chip *chip, u32 rtmr_idx, struct tpm_digest *digests);
int tdx_get_boot_measurements(struct tdx_boot_digests *boot_digests);
/* ./arch/x86/include/asm/tdx.h */
void ccel_record_eventlog(void *data, u8 index);
```

Tool and SDK Support

```
ACPI_TABLE_FILE = "/sys/firmware/acpi/tables/CCEL"
ACPI_TABLE_DATA_FILE = "/sys/firmware/acpi/tables/data/CCEL"
IMA_DATA_FILE = "/sys/kernel/security/integrity/ima/ascii_runtime_measurements"
# The name of the device in different kernel version
DEVICE_NODE_NAME_DEPRECATED = "/dev/tdx-attest"    # deprecated
DEVICE_NODE_NAME_1_0 = "/dev/tdx-guest"
DEVICE_NODE_NAME_1_5 = "/dev/tdx_guest"
```

To be replaced by *Trusted Security Module (TSM)* Interface : https://elixir.bootlin.com/linux/v6.8-rc2/source/drivers/virt/coco/tsm.c

Contribution 1:
RTMR Backend

- td_infor : rtmr
- tdreport: quoted event log

```
/**
 * struct td_info - TDX guest measurements and configuration.
 * @attr: TDX Guest attributes (like debug, spet_disable, etc).
 * @xfam: Extended features allowed mask.
 * @mrtd: Build time measurement register.
 * @mrconfigid: Software-defined ID for non-owner-defined configuration
 *              of the guest - e.g., run-time or OS configuration.
 * @mrowner: Software-defined ID for the guest owner.
 * @mrownerconfig: Software-defined ID for owner-defined configuration of
 *                 the guest - e.g., specific to the workload.
 * @rtmr: Run time measurement registers.
 * @reserved: Added for future extension.
 *
 * It contains the measurements and initial configuration of the TDX guest
 * that was locked at initialization and a set of measurement registers
 * that are run-time extendable. More details can be found in TDX v1.0
 * Module specification, sec titled "TDINFO_STRUCT".
 */
struct td_info {
    __u8 attr[8];
    __u64 xfam;
    __u64 mrtd[6];
    __u64 mrco  id[6];
    __u64 mrown  [6];
    __u64 mrownerconfig[6];
    __u64 rtmr[24];
    __u64 servtd_hash[6];
    __u64 reserved[8];
};
```

```
/*
 * struct tdreport - Output of TDCALL[TDG.MR.REPORT].
 * @reportmac: Mac protected header of size 256 bytes.
 * @tee_tcb_info: Additional attestable elements in the TCB are not
 *                reflected in the reportmac.
 * @reserved: Added for future extension.
 * @tdinfo: Measurements and configuration data of size 512 bytes.
 *
 * More details can be found in TDX v1.0 Module specification, sec
 * titled "TDREPORT_STRUCT".
 */
struct tdreport {
    struct reportmac reportmac;
    __u8 tee_tcb_info[239];
    __u8 reserved[17];
    struct td_info tdinfo;
};
```

```
/**
 * struct reportmac - TDX guest report data, MAC and TEE hashes.
 * @type: TDREPORT type header.
 * @reserv  eserved for future extension.
 * @cpu_svn: CPU security version.
 * @tee_tcb_info_hash: SHA384 hash of TEE TCB INFO.
 * @tee_td_info_hash: SHA384 hash of TDINFO_STRUCT.
 * @reportdata: User defined unique data passed in TDG.MR.REPORT request.
 * @reserved2: Reserved for future extension.
 * @mac: CPU MAC ID.
 *
 * It is MAC-protected and contains hashes of the remainder of the
 * report structure along with user provided report data. More details can
 * be found in TDX v1.0 Module specification, sec titled "REPORTMACSTRUCT"
 */
struct reportmac {
    struct tdreport_type type;
    __u8 reserved1[12];
    __u8 cpu_svn[16];
    __u8 tee_tcb_info_hash[48];
    __u8 tee_td_info_hash[48];
    __u8 reportdata[64];
    __u8 reserved2[32];
    __u8 mac[32];
};
```

```
struct tpm_digest {
    u16 alg_id;
    u8 digest[TPM_MAX_DIGEST_SIZE];
} __packed;

struct tpm_bank_info {
    u16 alg_id;
    u16 digest_size;
    u16 crypto_id;
};
```

Contribution 2:
Digest List

IMA hooks: ima_bprm_check, ima_file_mmap, and ima_file_check

Policy Location: /sys/kernel/security/ima/digestlist_policy
Measurement Location: /sys/kernel/security/ima/digestlist_measurements

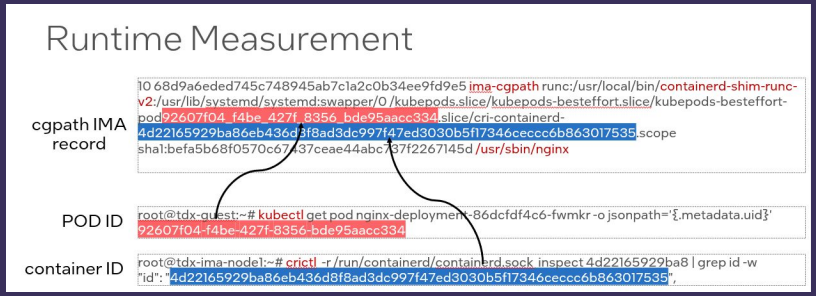
digestlist_policy format:
bprm /XXX/XXX/nvidia.ko
exe_file /XXX/XXX/file.file
config_file /XXX/XXX/file.file

digestlist_measurement format:
start with **RTMR[0]||RTMR[1],** extend to **PCR[8-15] map to RTMR[2]**
follow ima measurement list format
convert to canonical eventlog (in progress)
add IMA log to CCNP eventlog (in progress)

Contribution 2:
Digest List

two attestation modes supports:

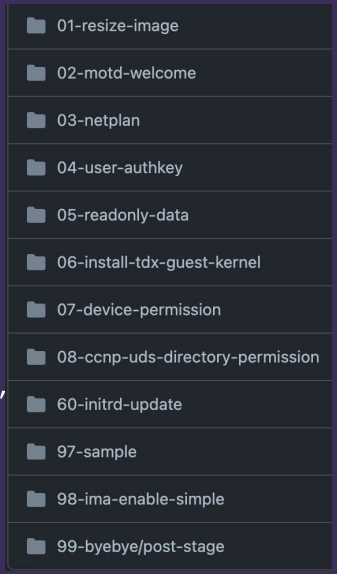
- **Local Attestation:**
  - Enabling IMA update and enabling i_version mount, Registering files hashes in i_version field as golden value for attestation for trusted domain components, distinguished by PODID-containerID
  - Code: Preregister golden values for trusted domain through cvm-rewriter https://github.com/cc-api/cc-trusted-vmsdk/tree/main/src/cvm-image-rewriter/plugins/98-ima-enable-simple
- **Remote Attestation: (in progress)**
  - Instead of Pre-load the golden values in the VM image, allow register golden value of trusted domain to remote attestor, and get attested there.



Contribution 3:
Trusted Domain

(defined in https://github.com/cc-api/cc-trusted-vmsdk)

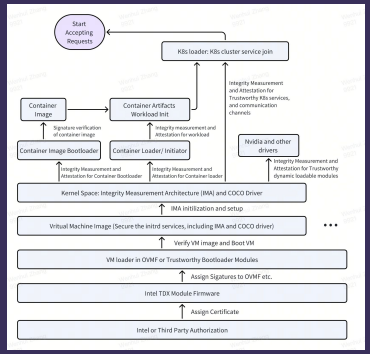
1. **Dynamic loaded modules**
   - Binary: `nvidia.ko`
2. **Container Runtimes:** containerd, containerd-shim and runc
   - Binary: `containerd`, `containerd-shim-runc-v2`, `runc`
   - Configuration File: `/etc/containerd/config.toml`
3. **K8S Management Plane:** kubelet
   - Binary: kubelet
   - Configuration File: /var/lib/kubelet/config.yaml and /etc/kubernetes/kubelet.conf
4. **CCNP services**
   - Binary: `CCNP userspace attestation tool, Remote Attestation Agent, KBS`
   - Code: https://github.com/cc-api/cc-trusted-api, https://github.com/cc-api/cc-trusted-vmsdk https://github.com/cc-api/trustauthority-kbs
5. **Trusted Container Launcher (in progress)**
   - Code: https://github.com/cc-api/cc-trusted-launcher
6. **Others:** `net`, `motd`, `passwd etc.`



Contribution 4:

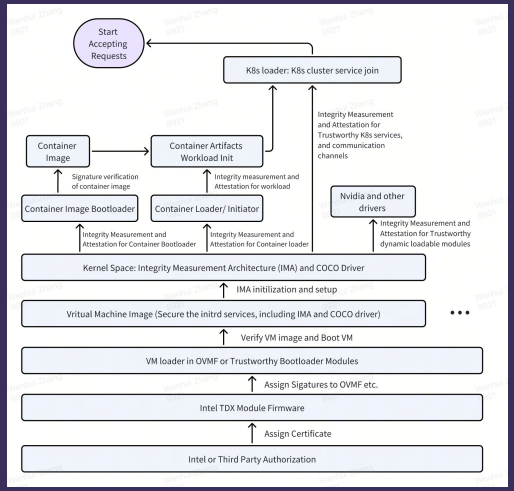
Trusted Container Launcher (In Progress)

```
Work as a daemonset: measure daemon and quote daemon
Start with RTMR[0]||RTMR[1]||RTMR[2]
Measurement:
 Container image loader (kubelet)
 Container launcher (containerd)
Attestation:
 Golden value of container images (artifacts) follows SPIFEE/SVID
 Containerd cmd with container name (PODID-containerID mapped to SVID)
Labels:
 Using containerID for container
 Using PODID for PODs
 Using groupLabels field (.group) for cluster
```

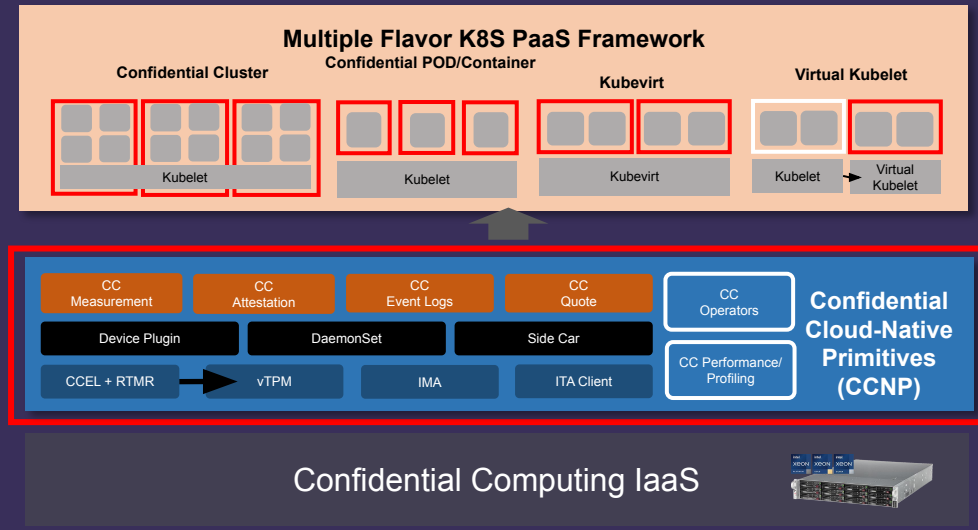


Summary

Code: https://github.com/cc-api
To be production ready for LLM and DB workloads by 06/24, upstream push by 12/24



Trust Chain



Thanks!

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