System Device Trees

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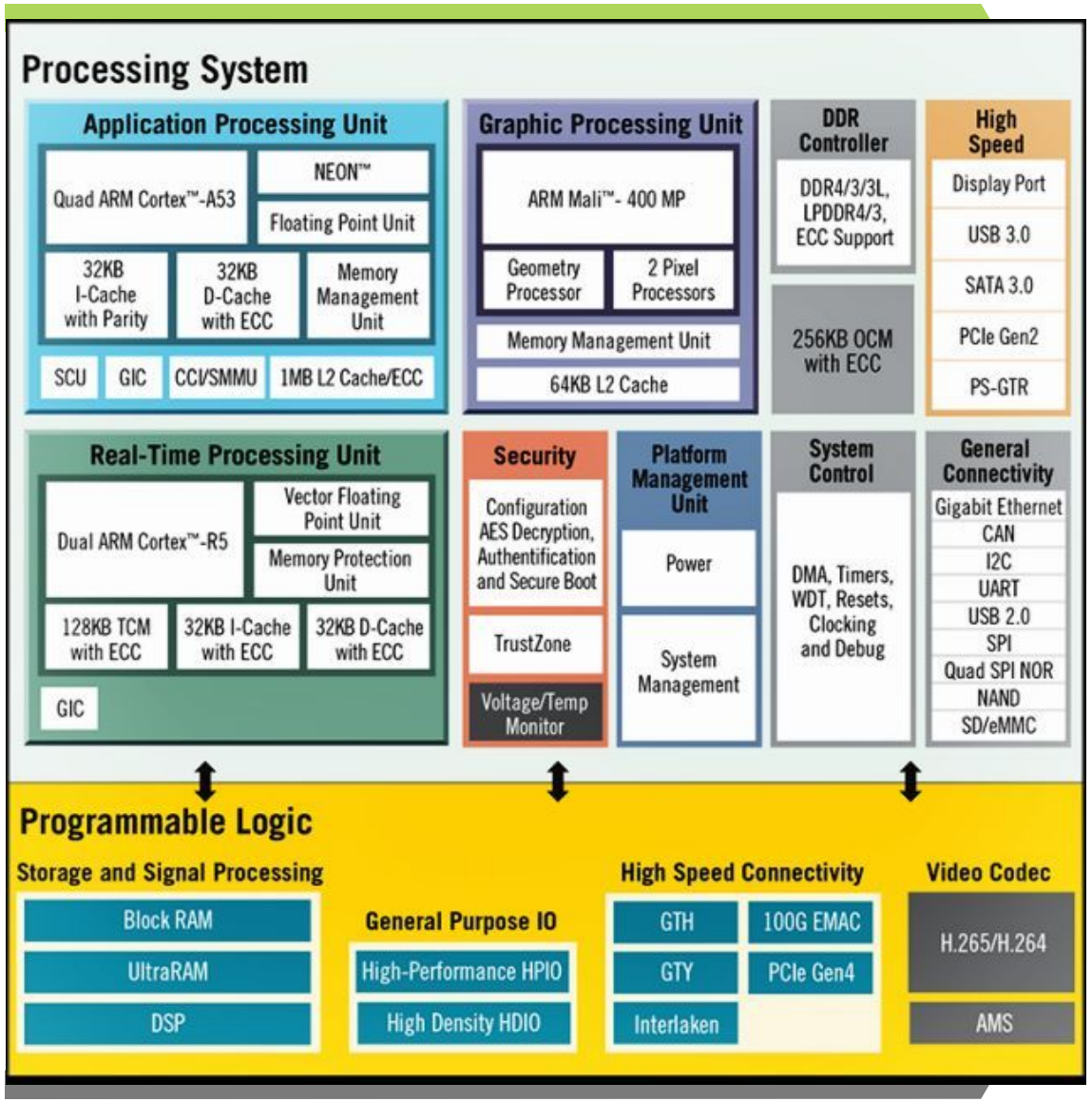
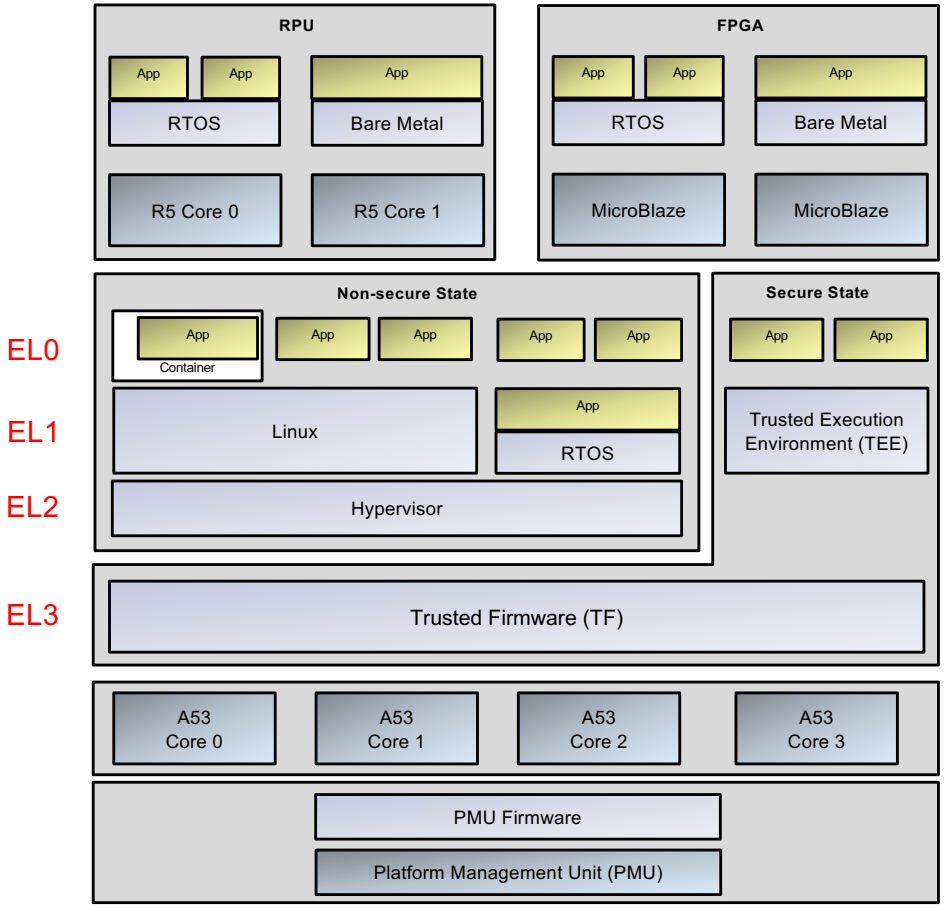


- **Modern SoCs are very heterogenous**
  - MPSoC: A53s, R5s, PMU, MicroBlazes
- **System Software needs a lot of HW info**
  - Memory allocated for each domain
    - Including shared pages
  - Devices assigned to each domain
  - Addresses of memory and registers
    - Same device can have different addresses
  - Topologies (clocks, busses, …)
- **Config info comes from different personas**
  - HW configuration – HW architect
    - The topology of the HW resources, including SoC resources, board resources, PL resources
  - Domain allocation – System Architect
    - Which HW resources are allocated to which domain
  - Domain configuration – BSP creator
    - OS specific information
- **Config happens at different times**
  - Compiled in during build time
    - Typical for RTOS, BM
  - Dynamically during boot time
    - Typical for Linux, Xen
  - Dynamically during runtime
    - Reassigning resources while running

Domains and Operating Environments

- Multiple core clusters
  - A53s, R5s, PMU, MicroBlazes
- Multiple Execution Levels (EL) on some cores
  - EL0 – User space
  - EL1 – OS
  - EL2 – Hypervisor
  - EL3 – Firmware
- Multiple Security Environments
  - TrustZone (TZ) – HW protecting resources (e.g. memory)
  - Trusted Execution Environment (TEE) – SEL1
- Domains
  - A Domain is a separate address space, including devices
  - Defined by different cores, Execution Levels and security environments
- Multiple Operating Environments (OE)
  - An OE is the system SW that runs in a Domain, including:
    - Linux (including Android), Free and commercial RTOS's
    - Bare metal (no OS), Hypervisors
    - Firmware/boot loaders – Trusted FW, PLM, PMU FW, uboot, ...



Problem Statement

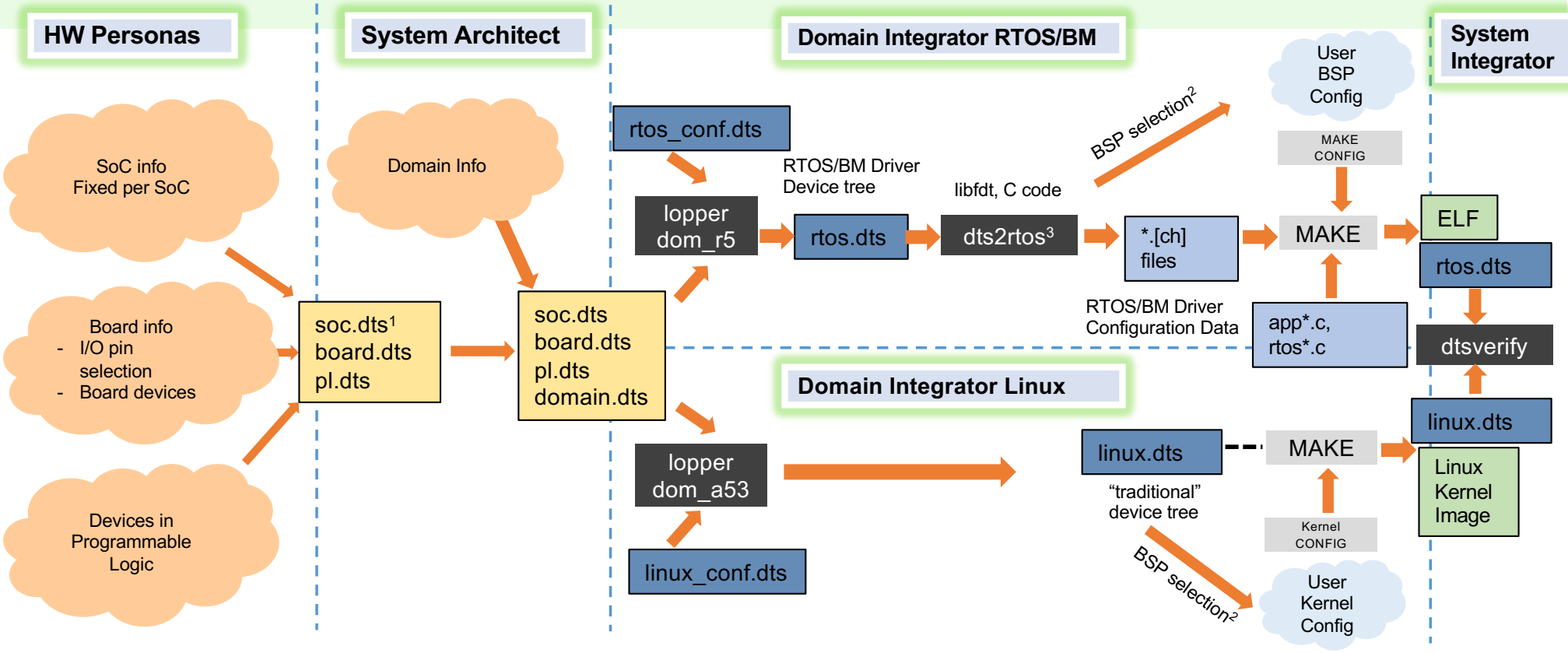
- Allocation and configuration of HW resources are complex
  - Typically done today in an ad-hoc way depending SoC and OS/Firmware
  - Especially tricky to define shared resources, such as OpenAMP/virtIO buffers
- Industry standards and common tools are needed to simplify configuration
  - Define resource allocation to Domains in one place, including shared buffers
  - Allows common flows for any SoC and Operating system/Firmware
  - Simplifies integration of OSes, Hypervisors and Firmware from different places and vendors
- Verification is critical at integration time and/or runtime
  - Make sure that different Domains are not erroneously using the same resources

Device Trees and System Device Trees

- **Device Trees (DTs) express HW information relevant to** Operating Environments
  - Been used by PPC and ARM SSW to define HW that can not be dynamically discovered
  - Used by uboot, Linux, Xen and increasingly being used by RTOS vendors
- **Device Trees describes HW nodes and topologies**
  - ***Traditional Device Trees are only describing the world seen from one Address Space***
- **Additional system level Device Tree information is proposed**
  - A **System Device Tree (S-DT)** describes all HW that later can be divided into different partitions
- System DT additions include two parts:

1. DeviceTree.org *specification* and tooling additions
   - Describing multiple cpu clusters and corresponding views of their address spaces
   - Enabling source-to-source translations by adding options to keep labels and comments
2. AMP *configuration* information
   - Resource allocation using *domains* and *resource groups*
   - Using the Device Tree `chosen` section to specify AMP configuration
   - Specification of shared resources, such as pages for virtIO buffers
   - Intent is to align with hypervisor information (e.g. Xen Dom0-less configuration)

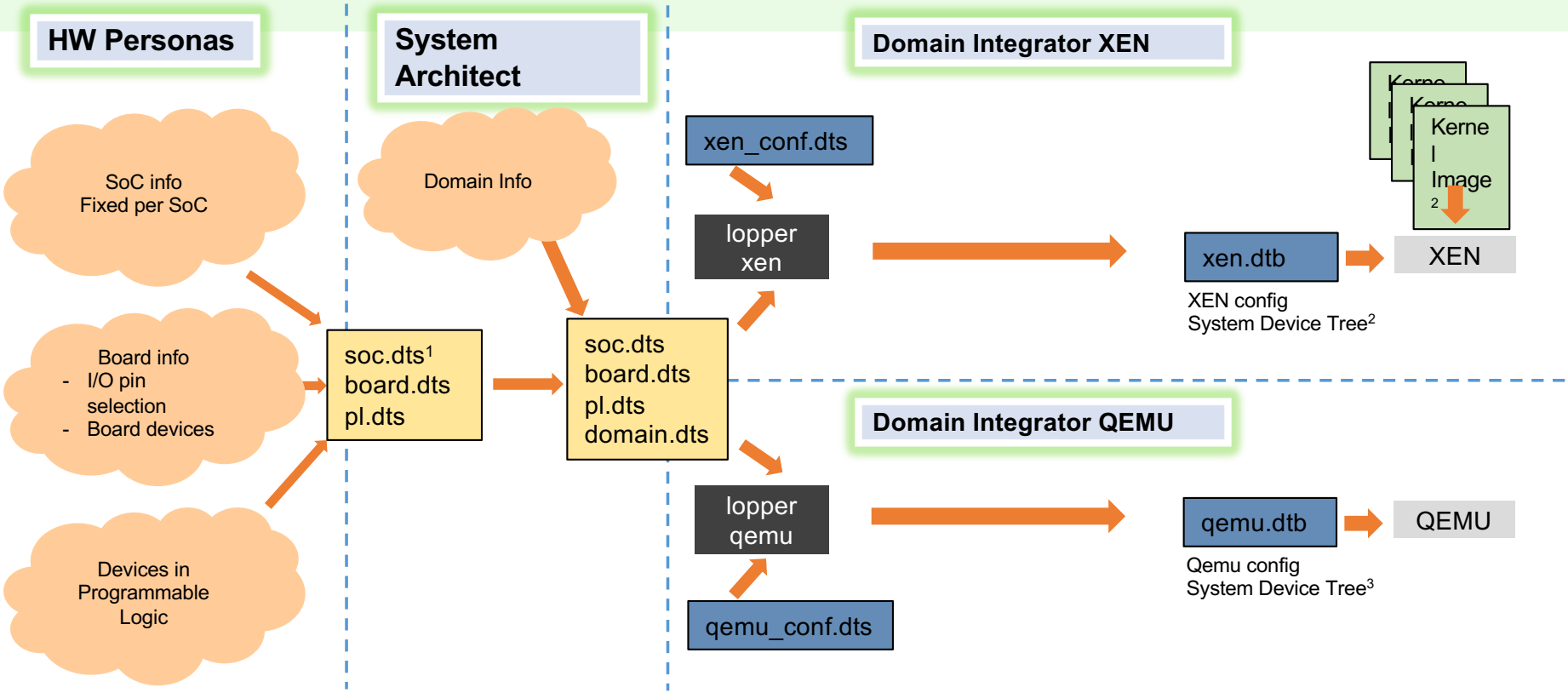
System Device Tree Data Flow (RTOS & Linux)



Standardized Data files | Open source tool | New open source code | RTOS specific data

1) .dts files before lopper is a System Device Tree
2) The .dts can be used to select drivers
3) RTOS specific transformations

System Device Tree Data Flow (Xen & QEMU)



Standardized Data files | Open source tool | New open source code | RTOS specific data

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1) .dts files before lopper is a System Device Tree
2) VM config from XEN or created separately
3) QEMU defines HW from a System Device Tree

System-DT Pruned to Linux DT Using Domains

System Device Tree (1/2)

```
/dts-v1/;
/ {
  compatible = "xlnx,zynqmp-zcu102",
               "xlnx,zynqmp";
  …
  cpus_a53 {
    #size-cells = <0x0>;
    #address-cells = <0x1>;
    compatible = "cpus,cluster";
    #ranges-size-cells = <0x1>;
    #ranges-address-cells = <0x1>;
    ranges-map =
      /* amba bus */
      <0xf0000000 &amba 0xf0000000 0x10000…
      /* tcm bus via amba bus */
      0xfe000000 &tcm_bus 0x0 0x1000>;
    cpu@0 {
        reg = <0x0>;
        compatible = "arm,cortex-a53";
        device_type = "cpu";
    };
    …
  };
  cpus_r5 {
    #size-cells = <0x0>;
    #address-cells = <0x1>;
    compatible = "cpus,cluster";
    #ranges-size-cells = <0x1>;
    #ranges-address-cells = <0x1>;
    ranges-map =
      /* amba */
      <0xf0000000 &amba 0xf0000000 0x10000…
      /* tcm bus */
      0x0 &tcm_bus 0x0 0x10000
      /* tcm bus via amba bus */
      0xfe000000 &tcm_bus 0x0 0x10000>;
    cpu@0 {
        reg = <0x0>;
        compatible = "arm,cortex-r5";
        device_type = "cpu";
    };
    …
```

System Device Tree (2/2)

```
  …
  memory {
    device_type = "memory";
    reg = <0x0 0x80000000 0x0
0x80000000>;
  };

  tcm_bus {
    compatible = "simple-bus";
    …
    tcm@e00000 {
      compatible = "mmio-sram";
      reg = <0xe00000 0x10000>;
    };
  };

  amba {
    compatible = "simple-bus";
    …
    ethernet@ff0e0000 {
      compatible = "cdns,zynqmp-gem";
      reg = <0x0 0xff0e0000 0x0 0x1000>;
      …
    };
    ahci@fd0c0000 {
      compatible = "ceva,ahci-1v84";
      reg = <0x0 0xfd0c0000 0x0 0x2000>;
      …
    };
  };
};
```

+

Domains

```
reserved-memory {
  #address-cells = <0x2>;
  #size-cells = <0x2>;
  ranges;
  memory_r5: memory_r5@0 {

    reg = <0x0 0x0 0x0 0x8000000>;
  };
  …
  rproc_0_dma: rproc@3ed400000 {
    compatible = "shared-dma-pool";
    reg = <0x0 0x3ed40000 0x0 0x100000>;

  };
};

chosen {
  …
  dom_r5 {
    …
    compatible = "openamp,domain-v1";
    memory = <0x0 0x0 0x0 0x8000000>;
    #cpus-mask-cells = <0x1>;
    cpus = <&cpus_r5 0x2 0x80000000>;
    access = <&memory_r5 0x1>,
             <&tcm_bus 0x0>,
             <&rproc_0_dma 0x1>,
             <&rproc_0_reserved 0x1>,
             <&ipi_mailbox_rpu0 0x31>;
  };
  dom_a53 {
    …
    compatible = "openamp,domain-v1";
    memory = <0x0 0x8000000 0x0 0x78000000>;
    #cpus-mask-cells = <0x1>;
    cpus = <&cpus_a53 0xf 0x2>;
    access = <&memory_a53 0x1>,
             <&tcm_bus 0x0>,
             <&ethernet@ff0e0000 0x0>,
             <&rproc_0_dma 0x1>,
             <&rproc_0_reserved 0x1>,
             <&ipi_mailbox_rpu0 0x13>;
  };
};
```

Linux Device Tree (A53)

```
/dts-v1/;
/ {
    compatible = "xlnx,zynqmp-zcu102",
                 "xlnx,zynqmp";
    …

    cpus {
        #size-cells = <0x0>;
        #address-cells = <0x1>;
        cpu@0 {
            reg = <0x0>;
            compatible = "arm,cortex-a53";
            device_type = "cpu";
        };
        …
    };
    memory {
        device_type = "memory";
        reg = <0x0 0xc0000000 0x0 0x40000000>;
    };

    amba {
        compatible = "simple-bus";
        …

        ethernet@ff0e0000 {
            compatible = "cdns,zynqmp-gem";
            reg = <0x0 0xff0e0000 0x0 0x1000>;
            …
        };
    };

    zynqmp-rpu {
        compatible = "xlnx,zynqmp-r5-
                      remoteproc-1.0";
    …
        mboxes = <&ipi_mailbox_rpu0 0>,
                 <&ipi_mailbox_rpu0 1>;
        mbox-names = "tx", "rx";
    };
```

Domains and Resource Groups

- A *domain* is a set of nodes defining an address space
  - Used to create a traditional DT to an OS like Linux
  - Domains can both refer to physical objects (CPUs, memory, devices) as well as and *domains*
  - Specified in the `chosen` section
  - Using the `compatible = "openamp,domain-v1"` attribute
- A *resource group* is a set of shared nodes grouped together
  - Devices that can be used by multiple domains
  - Memory areas that can be shared by multiple domains
  - Specified in the `chosen` section
  - Using the `compatible = "openamp,group-v1"` attribute
- Examples of domains:
  - A list of devices that could be shared between different domains
  - Shared pages and other resources used by VirtIO/rproc/rpmsg
  - A Linux domain running on the A53s including some memory and devices
  - A trusted FW/TZ accessing A53 domain plus more

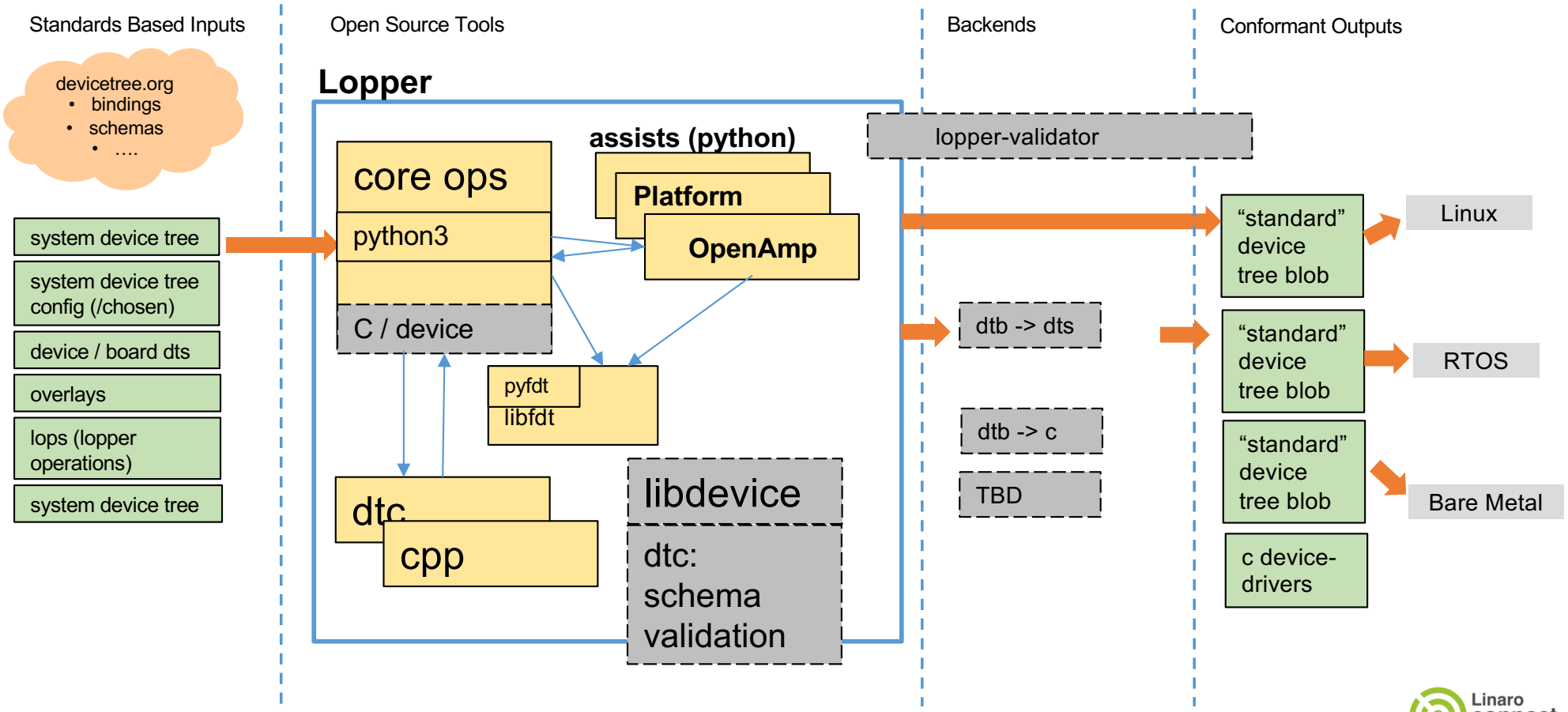
Domains (Out of date!)

```
chosen {
  …
  sh_devs {
    …
    /* Devices used from multiple domains */
    access = <&tcm_bus $ethernet &ahci>;
  };

  oamp_1 {
    …
    /* shared virtIO page */
    memory = <0x0 0x100000 0x0 0x1000>;
  };

  dom_a53 {
    …
    /* private memory for a53 domain */
    memory = <0x0 0x10000000 0x0 0x40000000>;
    /* all a53s + shared devs + OpenAMP mem
*/
    access = <&cpus_a53 &sh_devs &oamp1>;
  };

  dom_tz {
    …
    /* All of mem + a53 domain */
    memory = <0x0 0x0 0x0 0x80000000>;
    access = <&dom_a53 tz_dev>;
  }
  …
};
```

Open Source Tool (Lopper) to Manipulate S-DT

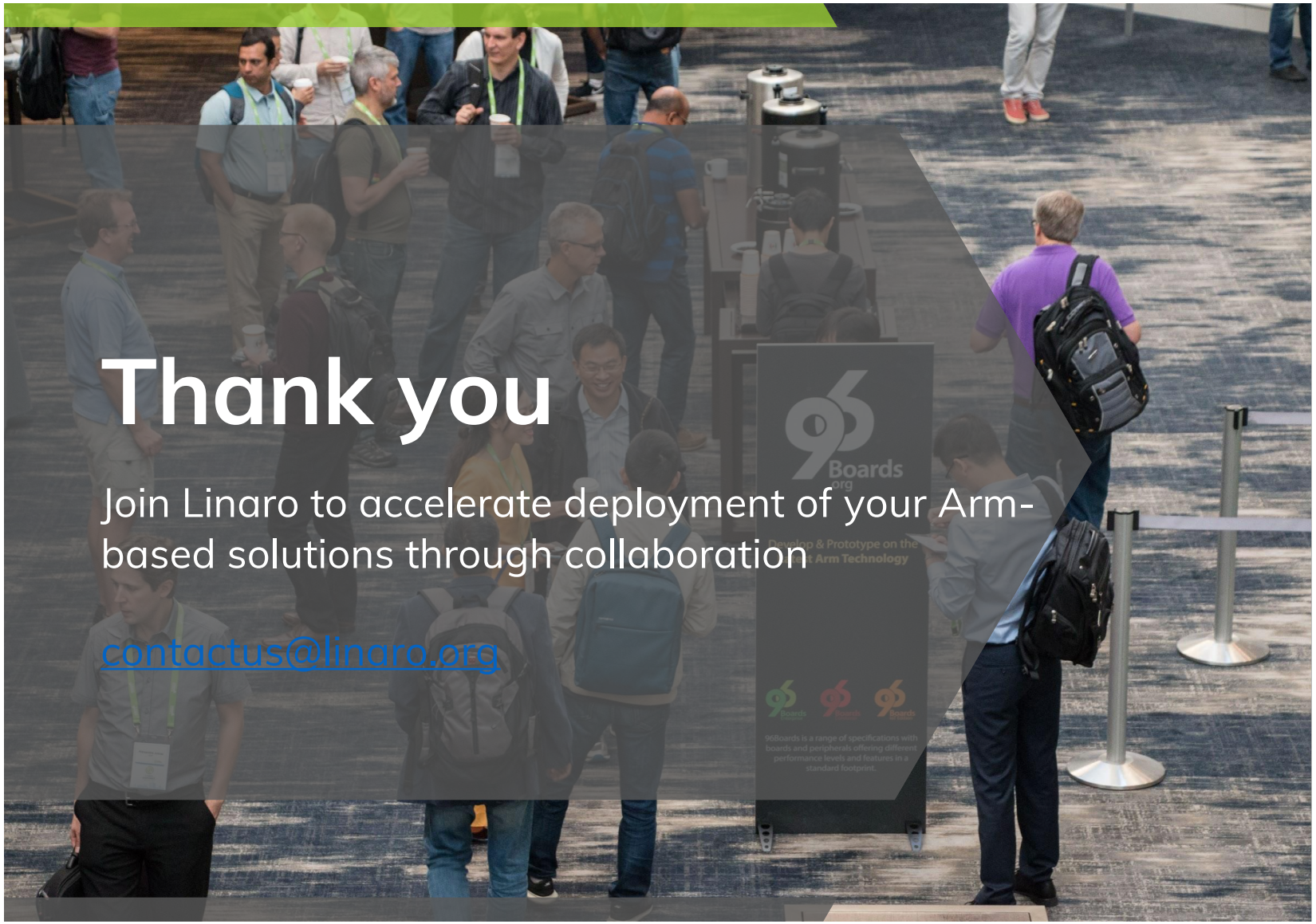
- Built on top of existing Device Tree tooling and libraries (DTC, libfdt)
- Manipulates S-DTs and DTS by
  - Merging/adding information like new nodes and new attributes (already exists in DTC)
    - Merge S-DTs from different places (SoC, board, FPGA, ...)
    - Includes suppressing nodes that are not pinned out to the board
  - Prunes System Device Trees to traditional/partitional Device Trees
    - Removes nodes not used, resolves address mapping issues
    - Other transformation (clocks, phandles, ...)
    - Use a *domain* configuration in a S-DT `chosen` section to select what to be kept/pruned
- Additional features
  - Extensible to add SoC vendor specific information, such as *remoteproc* info
  - Keeps as much as possible of original information, including labels and comments
  - Can create source output as well as binary output (dts and dtb)

Lopper Components



Interested?

- System Device Tree meeting at Connect 9:00 AM on Thursday
- Send me an email: tomase@Xilinx.com



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