# LTD20-205
## System Device Tree Project

2020-03-25

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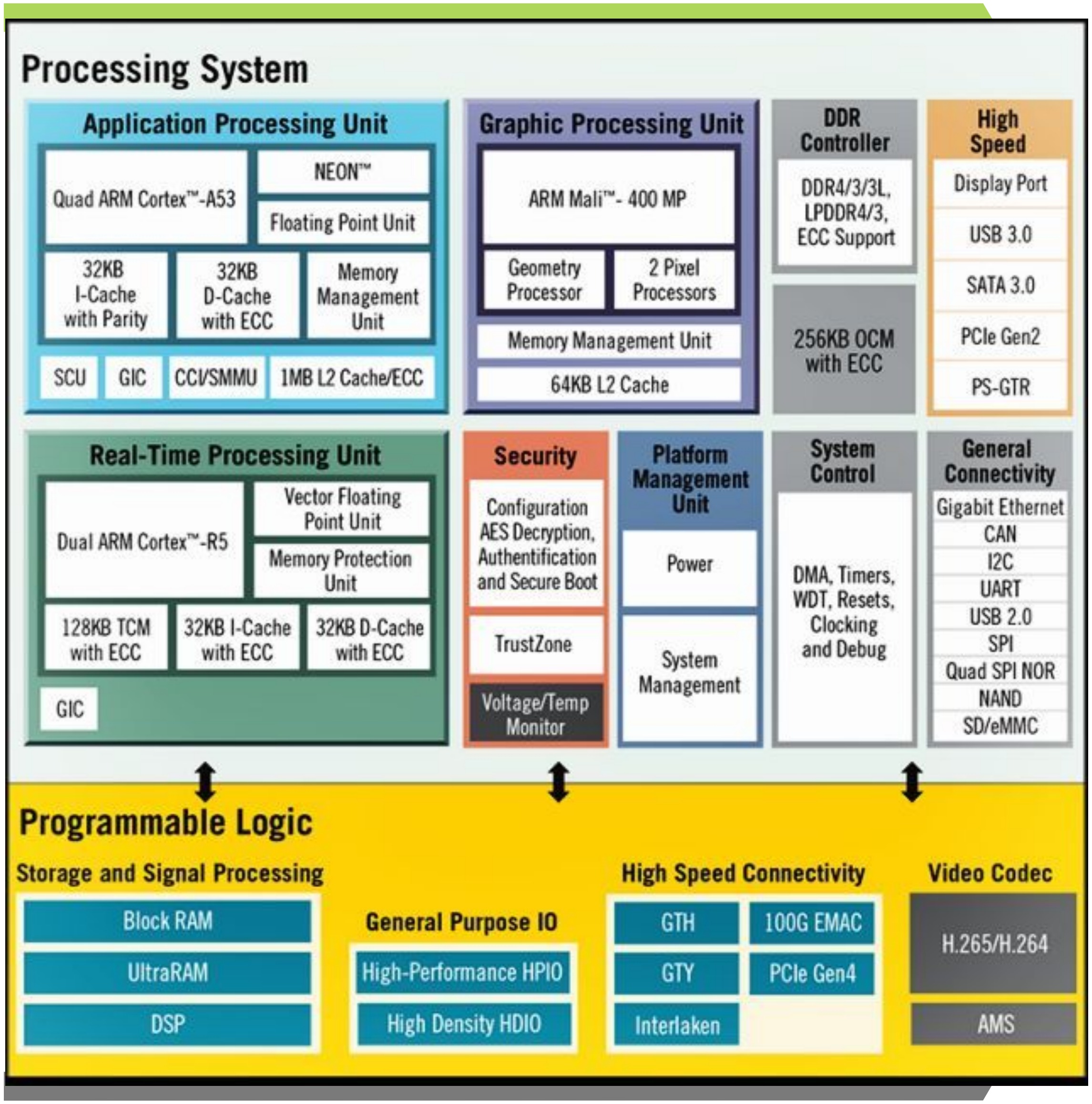
# What is a System Device Tree?




- **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, …)
- **Allocation and configuration is complex**
  - Typically done in an ad-hoc way
    - Editing Device Trees and #defines
  - Especially tricky for shared resources
    - E.g. shared pages for OpenAMP/virtIO
- **Industry standards and common tools needed**
  - One well-defined true source for all configuration
    - Common for Linux, firmware, RTOSes, etc.
  - Open source tooling to manipulate configuration
    - Split up allocated resources to "Execution Domains"

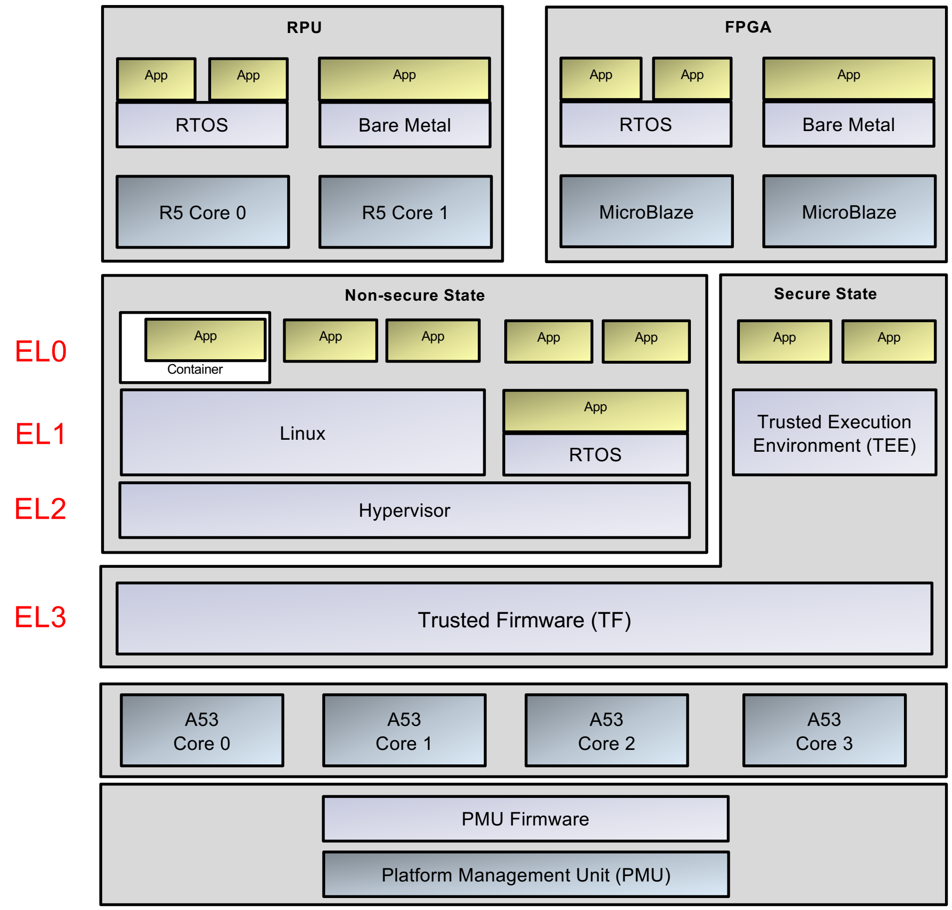
# Device Trees and System Device Trees

- **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 *Execution Domains*
     - Using the a special Device Tree 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)

# What is an “Execution Domain”?

# Execution Domains and Operating Environments

- Domains
  - A Domain is a separate address space, including devices
  - Defined by cores clusters, Execution Levels and security environments
- Core clusters – Heterogeneous cores
  - E.g. A53s, R5s, PMU, MicroBlazes
- Execution Levels (EL)
  - EL0 – User space EL1 – OS
  - EL2 – Hypervisor EL3 – Firmware
- Security Environments
  - TrustZone (TZ) – HW protecting resources (e.g. memory)
  - Trusted Execution Environment (TEE) – SEL1
- 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, ...

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# What’s the difference between System DT and DT?

# The current proposal: new concepts

- Hardware description
  - ***cpus,cluster***: multiple top-level nodes to describe heterogeneous CPU clusters
  - ***indirect-bus***: a new type of bus that does not automatically map to the parent address space
  - ***address-map***: a property to express different address mappings of CPUs clusters; it can map indirect-buses
- AMP Configuration
  - execution domains

# Hardware Description: an example

```
/* default cluster */
cpus {
          cpu@0 {
          };
          cpu@1 {
          };
};

/* additional R5 cluster */
cpus_r5: cpus-cluster@0 {
          compatible = "cpus,cluster";
          /* specifies address mappings */
          address-map = <0xf9000000 &amba_rpu 0xf9000000 0x10000>;
          cpu@0 {
          };
          cpu@1 {
          };
};

amba_rpu: indirect-bus@f9000000 {
          compatible = "indirect-bus";
};
```

# Why we have a default?

- It is convenient to have an execution domain that owns everything by default
- It is also very common: e.g. Linux running on a Cortex-A cluster
- It turns system device tree into an addition to device tree
- It makes it more natural to introduce system device tree concepts to the device tree spec
- It allows us to maintain compatibility with existing systems, i.e. Linux booting on system device tree

# How do we describe interrupts?

# Interrupts

- Multple clusters
- Each cluster sees only its own interrupt controller
- Other hardware hard-wired to a specific bus can be specified the same way

```
/* default cluster */
cpus {
};

/* additional R5 cluster */
cpus_r5: cpus-cluster@0 {
            compatible = "cpus,cluster";
            /* specifies address mappings */
            address-map = <0xf9000000 &amba_rpu 0xf9000000 0x10000>;
};

/* bus only accessible by cpus */
amba_apu: bus@f9000000 {
            compatible = "simple-bus";
            gic_a72: interrupt-controller@f9000000 {
            };
};

/* bus only accessible by cpus_r5 */
amba_rpu: indirect-bus@f9000000 {
            compatible = "indirect-bus";
            gic_r5: interrupt-controller@f9000000 {
            };
};
```

# Interrupts

All devices have interrupts routed to both interrupt controllers

```
amba: bus@f1000000 {
        compatible = "simple-bus";
        ranges;
        #interrupt-cells = <3>;
        interrupt-map-pass-thru = <0xffffffff 0xffffffff 0xffffffff>;
        interrupt-map-mask = <0x0 0x0 0x0>;
        interrupt-map = <0x0 0x0 0x0 &gic_a72 0x0 0x0 0x0>,
                        <0x0 0x0 0x0 &gic_r5 0x0 0x0 0x0>;

        can@ff060000 {
                        compatible = "xlnx,canfd-2.0";
                        reg = <0x0 0xff060000 0x0 0x6000>;
                        interrupts = <0x0 0x14 0x1>;
        };
};
```

# How do we dedicate *assignable* resources to CPUs clusters?

# Configuration: execution domains

- An **execution domain** is a collection of software, firmware, and board configurations that enable an operating system or an application to run a CPUs cluster.
  - ***cpus***: physical CPUs where the software is running
  - ***memory***: memory assigned to the domain
    - Memory ranges can be shared across multiple domains, e.g. for communication
  - ***access***: devices assigned to a domain

```
domains {
        openamp_r5 {
                compatible = "openamp,domain-v1";
                cpus = <&cpus_r5 0x2 0x80000000>;
                memory = <0x0 0x0 0x0 0x8000000
                 0x0 0x10000000 0x0 0x1000>;
                access = <&can@ff060000>;
        };
};
```

# How do we configure Bus Firewalls?

# Bus Firewalls & Device Assignment

- Devices are assigned to execution domains using ***access***
- ***memory*** + ***access*** have the information necessary to configure bus firewalls
  - Memory ranges dedicated to one execution domain
  - Devices dedicated to one execution domain
- In the example below, the bus firewall can be configured to allow access to the following address ranges only from the Cortex-R5 cluster:
  - 0 - 0x80000000
  - 0xff060000 - 0xff066000

```
domains {
        openamp_r5 {
                compatible = "openamp,domain-v1";
                cpus = <&cpus_r5 0x2 0x80000000>;
                memory = <0x0 0x0 0x0 0x8000000>;
                access = <&can@ff060000>;
        };
};
```

# Bus Firewalls & Priorities

- The bus firewall configuration can be derived from ***memory, access,*** and the capability of the bus firewall
  - It can be implemented as a backend to lopper
- Bus firewalls might not be able to protect everything
- We need to set ***priorities*** for bus firewall protection
- From one execution domain point of view:
  - Priorities for protecting my memory/MMIO regions from foreign accesses (most important)
  - Priorities for protecting others from my memory accesses
  - We might need higher granularities, to specify priorities per device, per memory range

```
domains {
        openamp_microblaze {
                compatible = "openamp,domain-v1";
                priority_self = <9>;
                memory = < … >
                access = < … >
        };
};
```

# What about *chosen* and *reserved-memory*?

# Chosen & Reserved-Memory

- ***chosen*** and ***reserved-memory*** are top-level nodes dedicated for configurations
- In system device tree, they are dedicated to the configuration of the ***default*** CPUs cluster
- Other execution domains have their own chosen and reserved-memory nodes:

```
/* configurations for the default cluster */
chosen {
};
reserved-memory {
};
/* execution domains configuration */
domains {
        openamp_r5 {
                compatible = "openamp,domain-v1";
                cpus = <&cpus_r5 0x2 0x80000000>;
                memory = <0x0 0x0 0x0 0x8000000>;
                access = <&can@ff060000>;
                chosen {
                        bootargs = "console=ttyPS0,115200";
                };
                reserved-memory {
                        […]
                };
        };
};
```

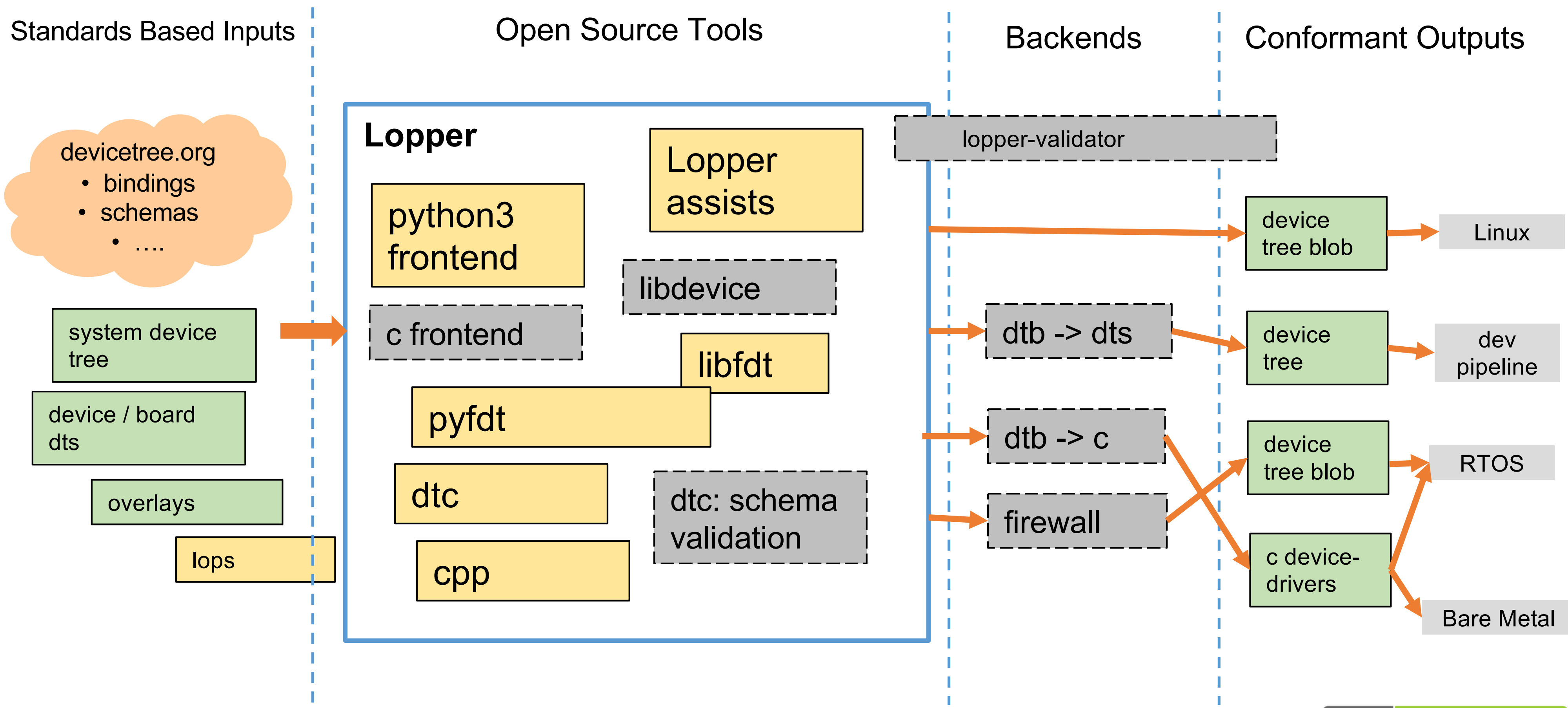
# What is “Lopper”?

# Lopper

- **Lopper**
  - Is a tool for manipulating System Device Trees
  - Primary goal is to produce standard devices trees to support existing platforms/OSs
    - Produces any number of outputs through plug-ins: device trees, generated code, custom, etc
  - Integrates with various development workflows
  - Is data driven (there is no magic!)
- **A few details:**
  - OpenSource, BSD-3 License
    - https://github.com/OpenAMP/open-amp/wiki/System-Device-Trees#Lopper
  - Written in python, using libfdt for tree manipulations
  - Works with dts and dtb inputs
  - Supports basic/simple operations (lops) and more complex python assist modules
    - Depending on the task, both can be used
  - Flexible output is provided via python backends
  - Performs validation and consistency checking during output

# What are the components of Lopper ?

# Lopper Components



# How do I run Lopper to create a traditional DT ?

# Generating a traditional DT (1/3)

- **Inputs:**
  - System Device tree
  - Domain node
  - Lopper operations (custom, built-in, or both)
- **Outputs:**
  - Standard Device tree
  - Optional: Custom device trees
- **What lopper does:**
  - Applies operations to the tree as specified in the lopper operations file (lops)
    - If specified, Finds the specified domain node
      - Applies logic based on the domain node
        - Built-ins, or via python assist
  - Performs built-in operations to remove non-standard elements
  - Outputs the modified system device tree
    - Either as a raw dump, or as a validated “pretty printed” version
    - Either way, the output is standard device tree

# Generating a traditional DT (2/3)

```
% lopper.py --pretty -i lops/lop-load.dts -i lops/lop-domain-r5.dts device-trees/system-device-tree-versal-v2.dts output/linux-r5.dts
```

```
SDT summary:
   system device tree: ['system-device-tree-versal-v2.dts']
   lops: ['lops/lop-load.dts', 'lops/lop-domain-r5.dts']
   output: output/foo.dts
...
[INFO]: deleting node /cpus
[INFO]: resetting all refcounts
[INFO]: tracking access to node /chosen/openamp_r5
[INFO]: tracking access to node /chosen
[INFO]: tracking access to node /cpus_r5
...
[INFO]: deleting node /amba/can@ff060000
[INFO]: deleting node /amba/can@ff070000
...
[INFO]: deleting node /amba/pci@fca10000
[INFO]: deleting node /amba/watchdog@fd4d0000
[INFO]: deleting node /amba/zynqmp_ipi
...
[INFO]: modify property found: /cpus_r5/::/cpus/
[INFO]: renaming /cpus_r5/ to cpus
...
[DBG+]: outfile is: linux.dtb
[DBG+]: output selected are: ['*']
[INFO]: dtb output format detected, writing .//linux.dtb
[INFO]: writing output dtb: .//linux.dtb
```

```
[INFO]: ------> processing lop: system-device-tree-v1,lop,output
[DBG+]: outfile is: linux-partial.dts
[DBG+]: output selected are: ['amba.*']
[DBG ]: node_copy_from_path: /amba_apu -> /amba_apu
[DBG ]: node_copy_from_path: /amba_rpu -> /amba_rpu
[DBG ]: node_copy_from_path: /amba -> /amba
[INFO]: dts format detected, writing .//linux-partial.dts
...
[INFO]: dts format detected, writing output/foo.dts
[DBG+]: [cpus:address-map] phandle replacement of: 0x20 with amba
[DBG+]: [cpus:address-map] phandle replacement of: 0x21 with amba_rpu
[DBG+]: [cpus:address-map] phandle replacement of: 0x22 with memory00000000
[DBG+]: [cpus:address-map] phandle: 0x23 not found, dropping 4 fields
[DBG+]: [cpus:address-map] phandle replacement of: 0x24 with tcmffe90000
[DBG+]: [interrupt-controller@f9000000:interrupt-parent] phandle replacement of: 0x5 with interrupt_controllerf9000000
[DBG+]: [smmu@fd800000:interrupt-parent] phandle replacement of: 0x5 with interrupt_controllerf9000000
[DBG+]: [timer:interrupt-parent] phandle replacement of: 0x5 with interrupt_controllerf9000000
[DBG+]: [interrupt-multiplex:interrupt-map] phandle replacement of: 0x5 with interrupt_controllerf9000000
[DBG+]: [interrupt-multiplex:interrupt-map] phandle replacement of: 0x25 with interrupt_controllerf9000000
[DBG+]: [ethernet@ff0c0000:interrupt-parent] phandle replacement of: 0x26 with interrupt_multiplex
[DBG+]: [ethernet@ff0c0000:iommus] phandle replacement of: 0x27 with smmufd800000
[DBG+]: [openamp_r5:cpus] phandle replacement of: 0x28 with cpus
[DBG+]: [openamp_r5:access] phandle replacement of: 0x29 with memory_r50
[DBG+]: [openamp_r5:access] phandle replacement of: 0x24 with tcmffe90000
[DBG+]: [openamp_r5:access] phandle replacement of: 0xb with ethernetff0c0000
[DBG+]: [zynqmp-power:interrupt-parent] phandle replacement of: 0x26 with interrupt_multiplex
```

# Generating a traditional DT (3/3)

```
% lopper.py --pretty -i lops/lop-load.dts -i lops/lop-domain-r5.dts device-trees/system-device-tree-versal-v2.dts output/linux-r5.dts
```

```
% cat system-device-tree-versal-d2.dts | grep { | wc -l
84

% cat device-trees/system-device-tree-versal-v2.dts | grep -A 10 "cpus {"
        cpus: cpus {
                #address-cells = <0x1>;
                #size-cells = <0x0>;
                #cpus-mask-cells = <0x1>;
                compatible = "cpus,cluster";

                cpu@0 {
                        compatible = "arm,cortex-a72", "arm,armv8";
```

```
% cat output/linux-r5.dts | grep { | wc -l
41

% cat output/linux-r5.dts | grep -A 10 "cpus {"
        cpus: cpus {
                #address-cells =  <0x1>;
                #size-cells =  <0x0>;
                #cpus-mask-cells =  <0x1>;
                compatible = "cpus,cluster";
                #ranges-size-cells =  <0x1>;
                #ranges-address-cells =  <0x1>;
                address-map =  <0xf1000000 &amba 0xf1000000 0xeb00000 0xf9000000 &amba_rpu 0xf9000000 0x10000 0x0 &memory00000000 0x0 0x80000000 0x0 &tcmffe90000 0xffe90000 0x10000>;
                phandle =  <0x28>;
                cpu@1 {
                        compatible = "arm,cortex-r5";
```

# Lopper: RTOS without DT support ?

# Lopper and non-DT aware OSs (1/2)

- **Inputs:**
  - System Device tree or Standard device tree
  - Optional: Domain node
  - Lopper operations (custom, built-in, or both)
  - Lopper assist module for the OS
- **Outputs:**
  - Device tree: partial, standard or unmodified
  - Code / headers for the OS
- **What lopper does:**
  - Applies operations to the tree as specified in the lopper operations file (lops)
    - Calls input/output assists specific to the target OS
  - Performs built-in operations to remove non-standard elements
  - Outputs the Device tree
    - Either as a raw dump, or as a validated “pretty printed” version
  - Outputs OS specific modules based on tree manipulations and output assists

# Lopper and non-DT aware Oss (2/2)

```
% lopper.py -f --pretty -i lops/lop-load.dts -i lops/safety-critical.dts
device-trees/system-device-tree-versal-v2.dts output/rtos-header.h
```

```
/* Lopper RTOS header generation */

#define cpus = "236"
#define cpus_cpu0 = "464"
#define cpus_cpu1 = "540"
#define cpu_opp_table = "620"
#define cpu_opp_table_opp00 = "700"
#define cpu_opp_table_opp01 = "768"
#define cpu_opp_table_opp02 = "836"
#define cpu_opp_table_opp03 = "904"
#define dcc = "976"
…
```

```
struct _cpus {
    int _cpus_cpu0;
    int _cpus_cpu1;
}
struct _cpu_opp_table {
    int _cpu_opp_table_opp00;
    int _cpu_opp_table_opp01;
    int _cpu_opp_table_opp02;
    int _cpu_opp_table_opp03;
}
```

# How Do I Engage with System Device Trees?

- System Device Tree project is part of the Linaro Device Tree Evolution Project
- Driven under the OpenAMP umbrella
  - Includes silicon vendors, OS vendors and others
  - Openampproject.org
- Join the mailing list
  - https://lists.openampproject.org/mailman/listinfo/system-dt
- Be part of the regular discussions
  - https://github.com/OpenAMP/open-amp/wiki/System-DT-Meeting-Notes-2020

# Thank you

Accelerating deployment in the Arm Ecosystem