devicetree: kernel internals and practical troubleshooting

There have been many presentations on what a devicetree looks like and how to create a devicetree. This talk instead examines how the Linux kernel uses a devicetree. Topics include the kernel devicetree framework, device creation, resource allocation, driver binding, and connecting objects. Troubleshooting will consider initialization, allocation, and binding ordering; kernel configuration; and driver problems.

Frank Rowand, Sony Mobile Communications

October 15, 2014

141010_2019

CAUTION

The material covered in this presentation is kernel version specific and is actively evolving

Most information describes 3.15-rc1 – 3.16-rc7

In cases where arch specific code is involved,
I will be looking at arch/arm/

Chapter 1

Device tree

what is device tree?

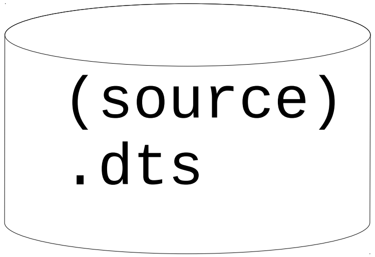
“A device tree is a tree data structure with nodes that describe the devices in a system. Each node has property/value pairs that describe the characteristics of the device being represented. Each node has exactly one parent except for the root node, which has no parent.”
(ePAPR v1.1)

what is device tree?

“A device tree is a tree data structure with nodes that describe the devices in a system. Each node has property/value pairs that describe the characteristics of the device being represented. Each node has exactly one parent except for the root node, which has no parent.”
(ePAPR v1.1)

A device tree describes hardware that can not be located by probing.

DT data life cycle



(source)
.dts

.dts - device tree source file

```
/ {   /* incomplete .dts example */

  model = "Qualcomm APQ8074 Dragonboard";
  compatible = "qcom,apq8074-dragonboard";
  interrupt-parent = <&intc>;

  soc: soc {
     ranges;
     compatible = "simple-bus";

     intc: interrupt-controller@f9000000 {
        compatible = "qcom,msm-qgic2";
        interrupt-controller;
        reg = <0xf9000000 0x1000>,
              <0xf9002000 0x1000>;

     console: serial@f991e000 {
        compatible = "qcom,msm-uartdm-v1.4", "qcom,msm-uartdm";
        reg = <0xf991e000 0x1000>;
        interrupts = <0 108 0x0>;
     };
```

.dts - device tree source file

Thomas Pettazzoni's ELC 2014 talk
“Device Tree For Dummies” is an excellent introduction to

- device tree source
- boot loader mechanisms
- much more!

http://elinux.org/images/f/f9/
Petazzoni-device-tree-dummies_0.pdf

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Petazzoni-device-tree-dummies_0.pdf

.dts - device tree source file

```
/ {   /* incomplete .dts example */          <--- root node

   model = "Qualcomm APQ8074 Dragonboard";   <--- property
   compatible = "qcom,apq8074-dragonboard";  <--- property
   interrupt-parent = <&intc>;               <--- property, phandle

   soc: soc {                                <--- node
      ranges;                                <--- property
      compatible = "simple-bus";             <--- property

      intc: interrupt-controller@f9000000 {  <--- node, phandle
         compatible = "qcom,msm-qgic2";      <--- property
         interrupt-controller;               <--- property
         reg = <0xf9000000 0x1000>,          <--- property
               <0xf9002000 0x1000>;

      serial@f991e000 {                      <--- node
         compatible = "qcom,msm-uartdm-v1.4", "qcom,msm-uartdm";
         reg = <0xf991e000 0x1000>;          <--- property
         interrupts = <0 108 0x0>;           <--- property
      };
   };
};
```

Key vocabulary

nodes

- the tree structure
- contain properties and other nodes

properties

- data values providing information about a node

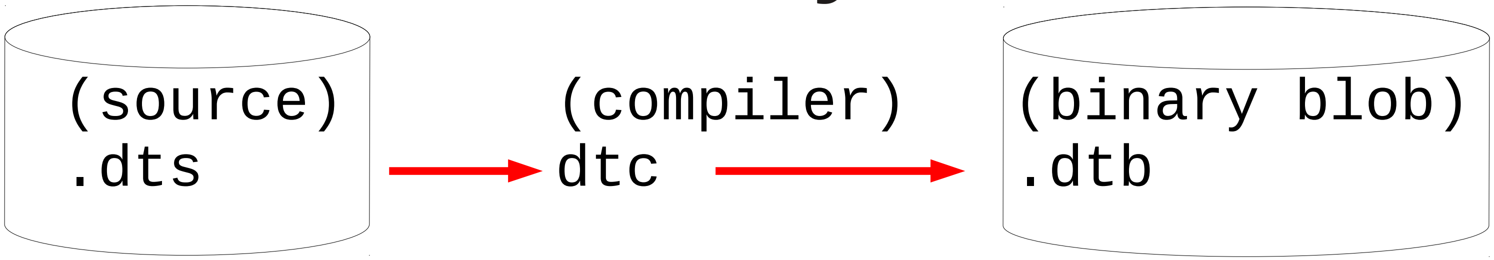
node '/': property 'compatible'

- will be used to match a machine_desc entry

other nodes: property 'compatible'

- will be used to match a driver

DT data life cycle

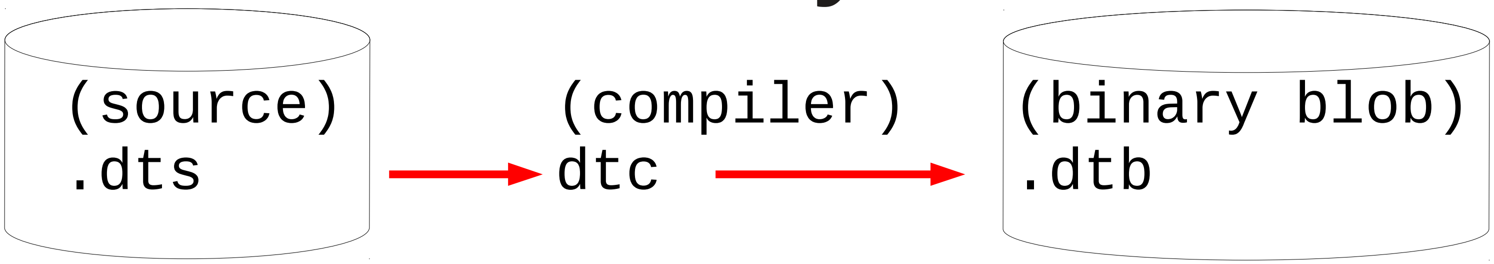


(source)
.dts

(compiler)
dtc

(binary blob)
.dtb

DT data life cycle



(source)
.dts

(compiler)
dtc

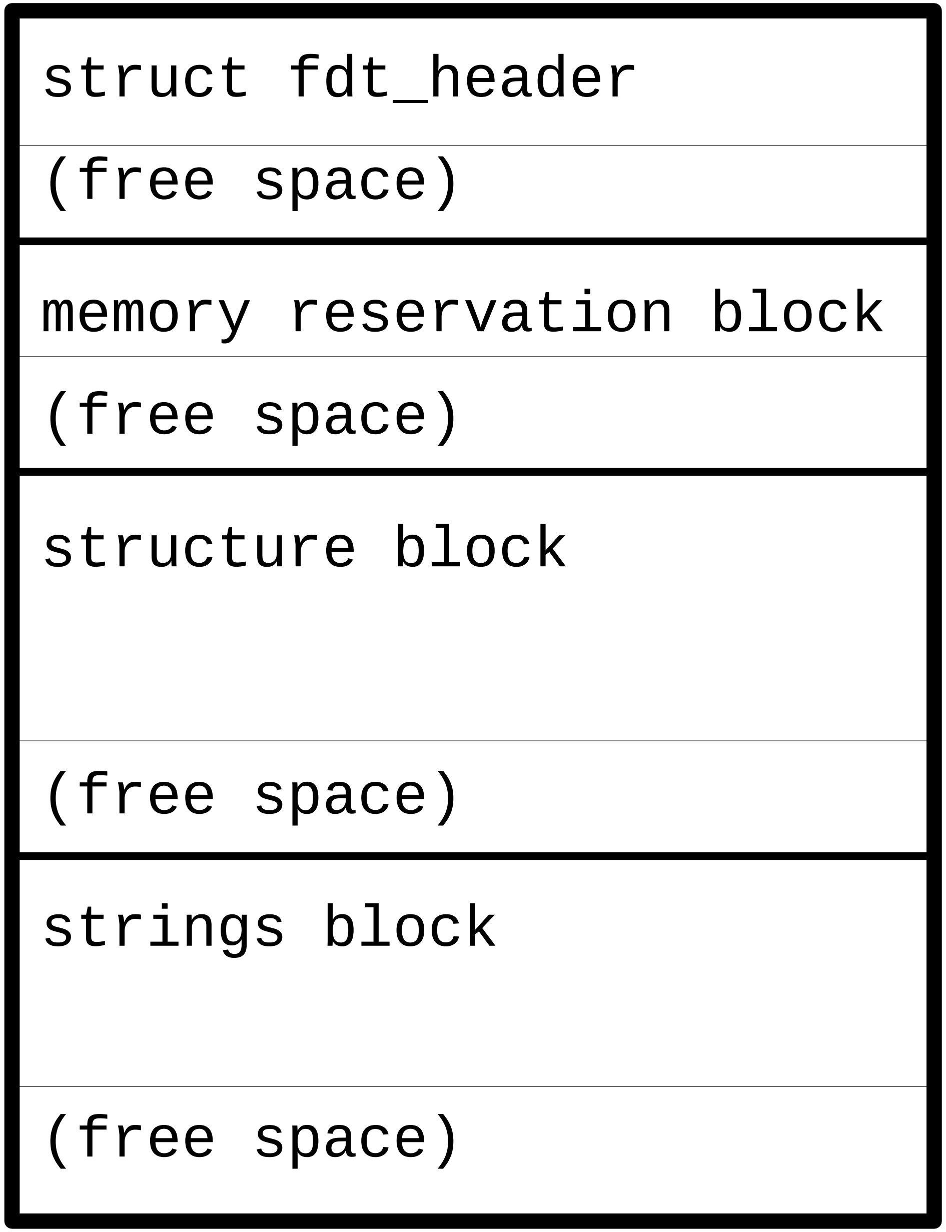
(binary blob)
.dtb

Binary Blob format

A “flat” format

Access via serial scan and offsets

Binary Blob format



struct fdt_header

(free space)

memory reservation block

(free space)

structure block

(free space)

strings block

(free space)

info
offsets to blocks
section sizes

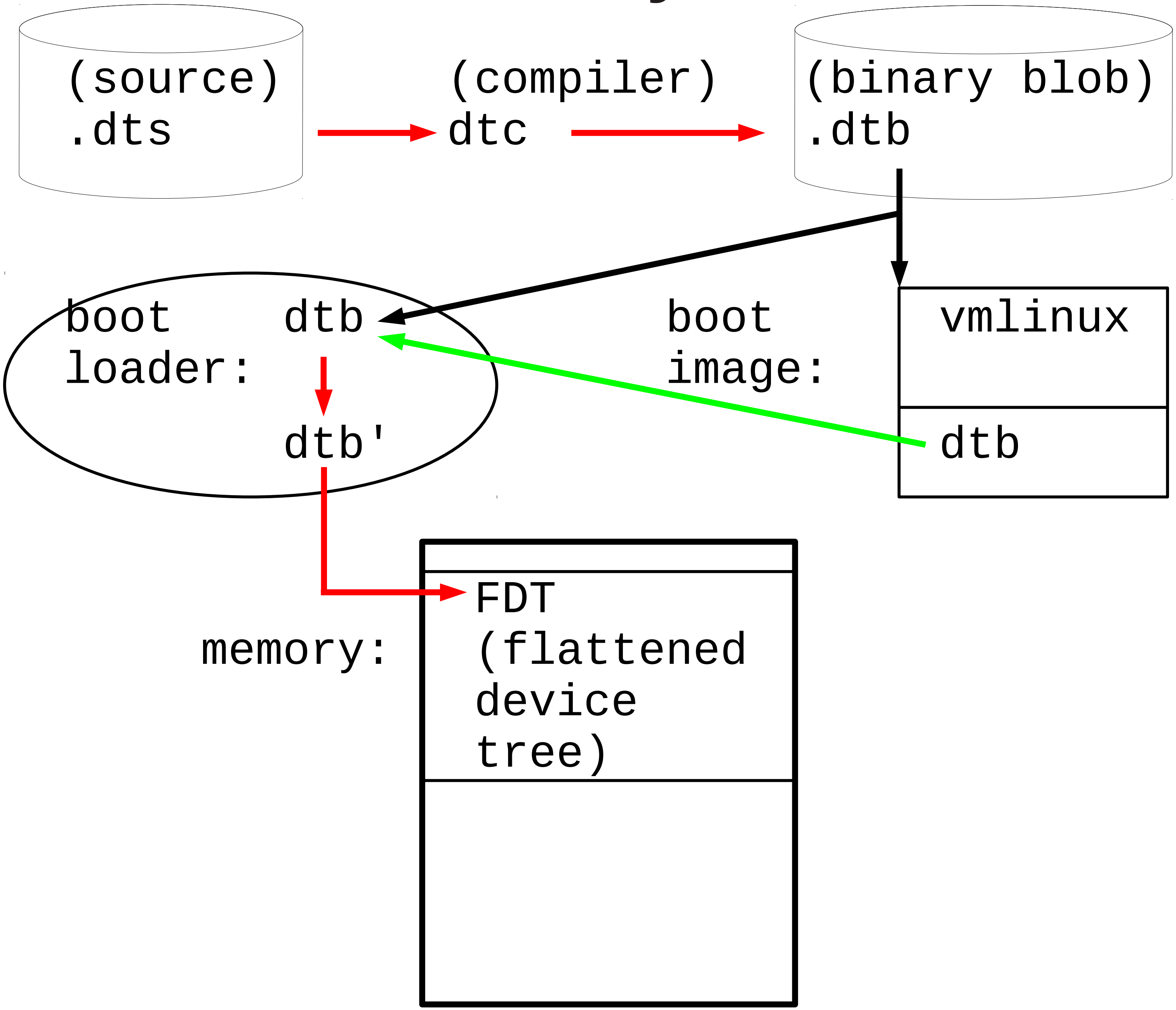
{address, size} tuples

nested nodes
- name embedded

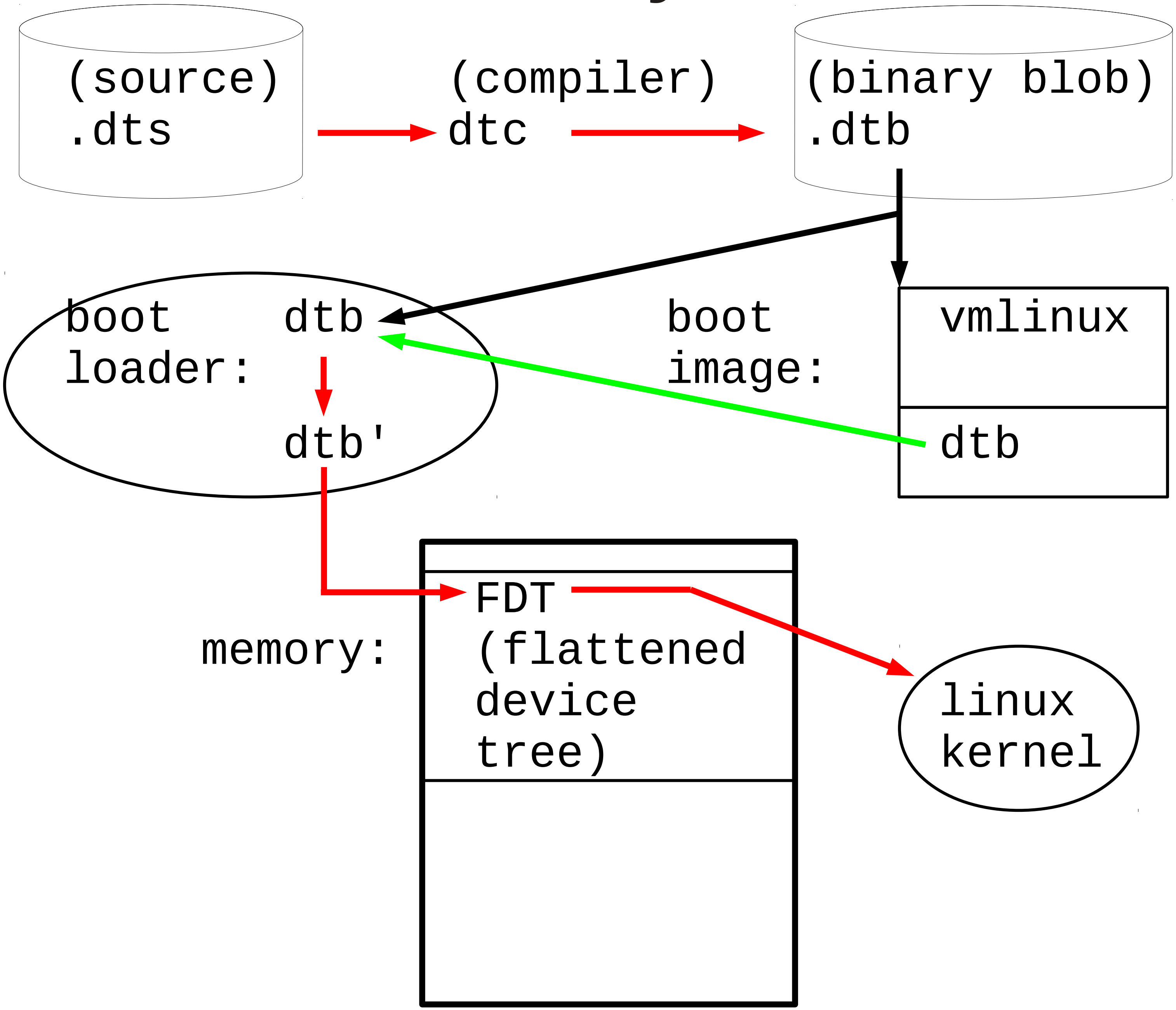
properties nested in nodes
- values embedded
- names are offsets in 'strings'

property names
- null terminated strings
- concatenated

DT data life cycle



DT data life cycle



(source)
.dts

(compiler)
dtc

(binary blob)
.dtb

boot
loader:

dtb

dtb'

boot
image:

vmlinux

dtb

memory:

FDT
(flattened
device
tree)

linux
kernel

Flattened Device Tree format

A “flat” format.

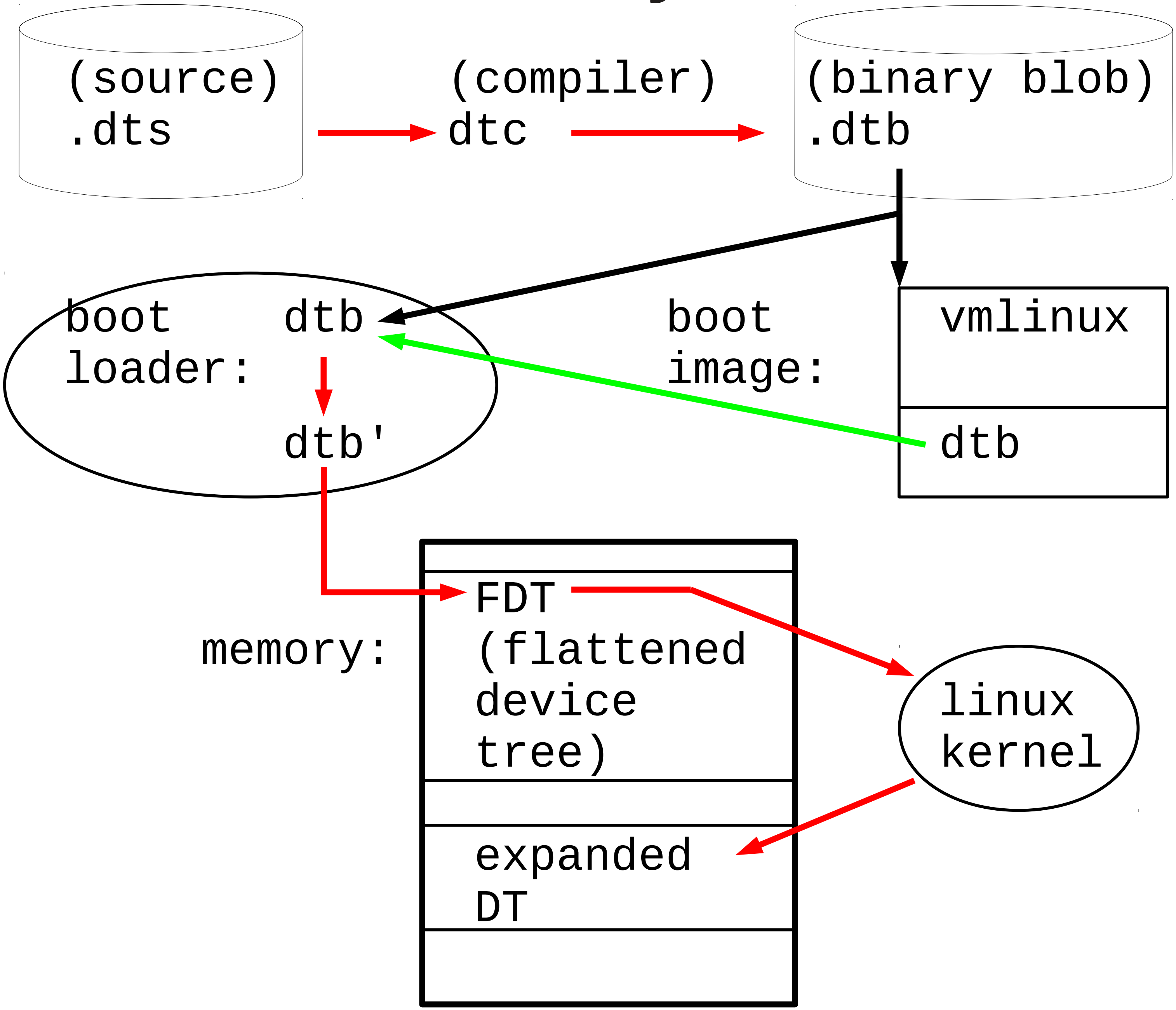
Access via serial scan and offsets
using fdt_*() functions.

Flattened Device Tree format

A “flat” format.

Access via serial scan and offsets
using fdt_*() functions.

DT data life cycle



Expanded format

A “computer-sciency” data structure

Plan is to change implementation soon

- interfaces to access data should not change
- implications for DT usage should not change

Expanded format

A “computer-sciency” data structure

Exact details not too interesting unless you are maintaining the DT internals, so I will mostly not leave the slides up long enough for you to read the details. If you are interested, read the slides at home.

I will be trying to emphasize concepts instead of details.

Expanded format

A tree data structure

Access and modified via tree operations using of_*() functions

Access all nodes via a linked list

Created during boot

Nodes and properties can be added or deleted after boot

Expanded format

A tree data structure

Access and modified via tree operations using of_*() functions

Access all nodes via a linked list

Created during boot

Nodes and properties can be added or deleted after boot

Expanded format

tree of struct device_node

```
struct device_node {
   const char *name;
   const char *type;
   phandle phandle;
   const char *full_name;

   struct  property *properties;
   struct  property *deadprops;
   struct  device_node *parent;
   struct  device_node *child;
   struct  device_node *sibling;
   struct  device_node *next;
   struct  device_node *allnext;
   struct  kobject kobj;
   unsigned long _flags;
   void    *data;
#if defined(CONFIG_SPARC)
   ...
#endif
};
```

Expanded format

tree of struct device_node

```
struct device_node {






   struct  property *properties;

   struct  device_node *parent;
   struct  device_node *child;
   struct  device_node *sibling;

   struct  device_node *allnext;







};
```

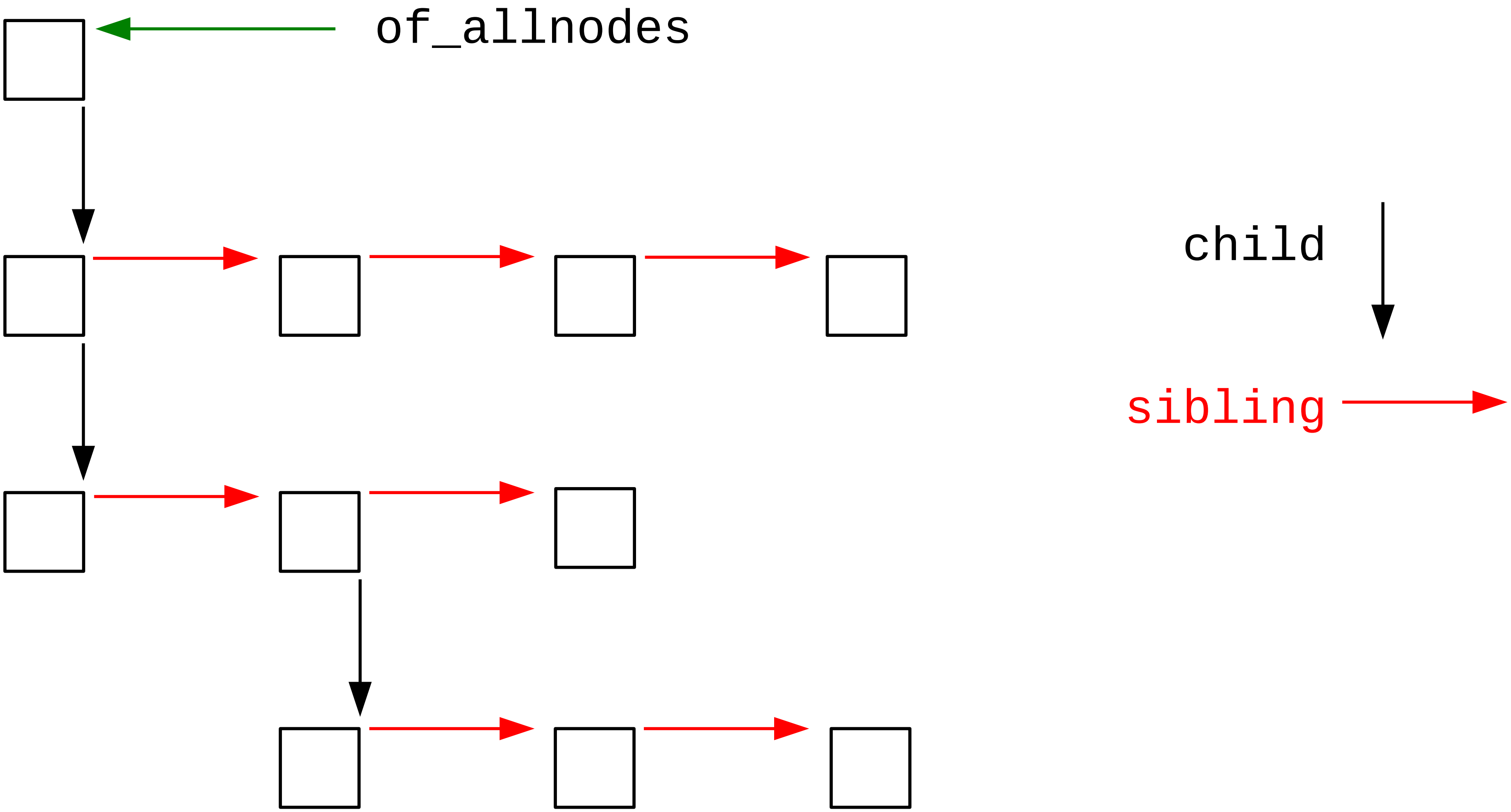
Expanded format `tree of struct device_node`

Tree pointers

- child pointer
- sibling pointer

Expanded format

tree of struct device_node



of_allnodes

child

sibling

Expanded format

`tree of struct device_node`

Tree pointers

- child pointer
- sibling pointer

Used to find node by tree search

- of_find_node_by_path()

Expanded format `tree of struct device_node`

Global linked list pointer

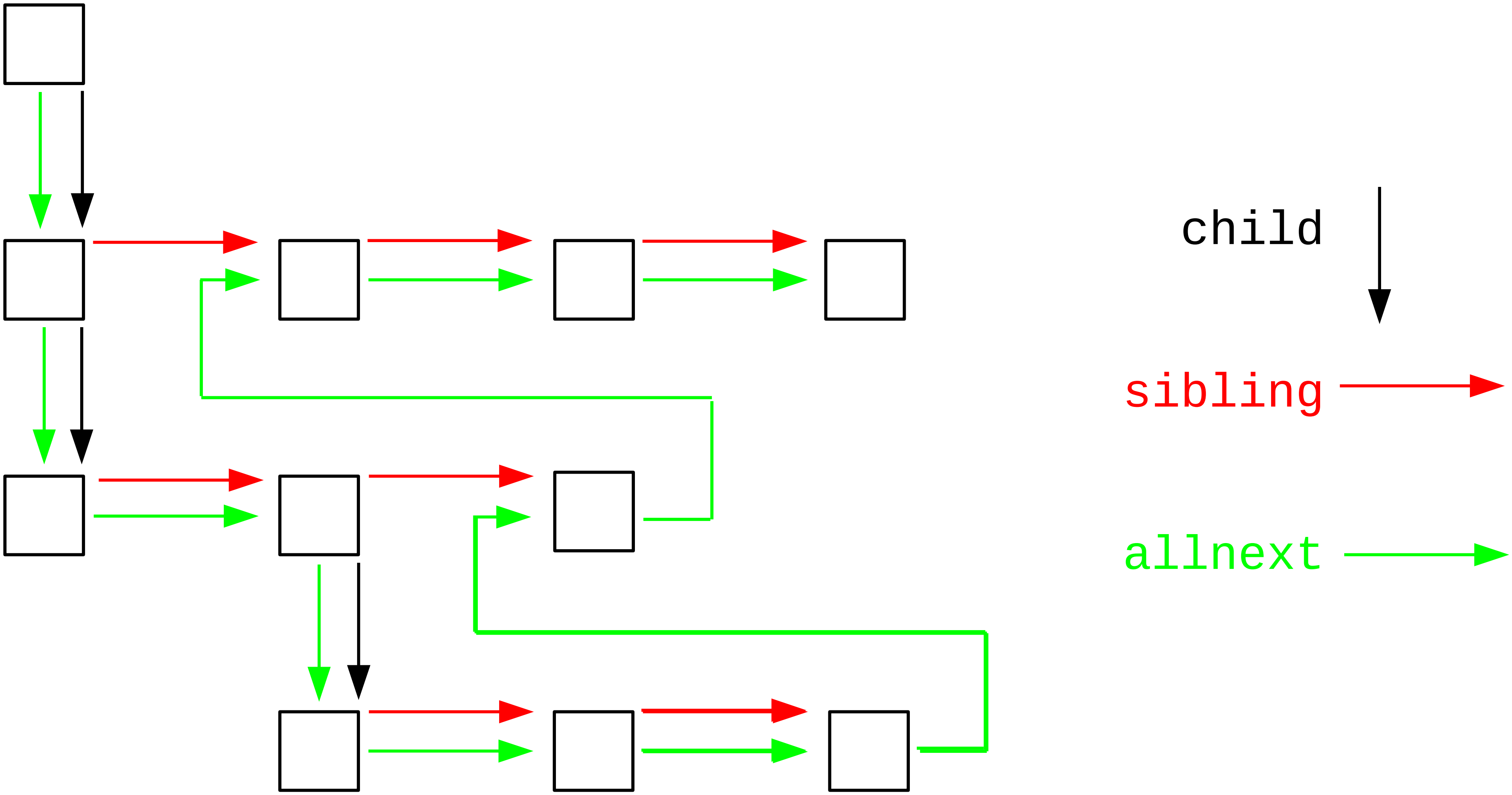
allnext pointer

removal targeted for 3.19

- API: unchanged
- implementation: depth first traversal of tree

Expanded format

tree of struct device_node



child

sibling

allnext

allnext linked list

Follows a depth first traversal of the tree

After boot: YES

After dynamic node addition: NO

To be safe, think of allnext as a randomly ordered linked list of all nodes.

allnext linked list - internal usage

Common pattern:

```
of_find_by_XXX(struct device node *from, …)
{
   np = from ? from->allnext : of_allnodes;
      for (; np; np = np->allnext)
         …
```

If 'from' is NULL then search from of_allnodes, else search from a specific starting point

allnext linked list - internal usage

Common pattern:

```
of_find_by_XXX(struct device node *from, …)
{
   np = from ? from->allnext : of_allnodes;
      for (; np; np = np->allnext)
         …
```

If 'from' is NULL then search from of_allnodes, else search from a specific starting point

allnext linked list - internal usage

Find nodes by attribute

```
struct device_node {
   const char *name;
   const char *type;
   phandle phandle;
   const char *full_name;
```

allnext linked list - internal usage

Find nodes by attribute

of_find_node_by_name (*from, …)
of_find_node_by_type (*from, …)

of_find_node_by_phandle (handle)

handle is unique, so *from not needed

of_find_node_with_property (*from, …)

traverse allnext and properties

allnext linked list - internal usage

Find nodes by attribute

of_find_node_by_name (*from, …)

of_find_node_by_type (*from, …)

of_find_node_by_phandle (handle)

handle is unique, so *from not needed

of_find_node_with_property (*from, …)

traverse allnext and properties

allnext linked list

Properties 'name' and 'device_type' are special.

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

In addition to existing on the node's properties list, these properties are hoisted into:

device_node.name

device_node.type

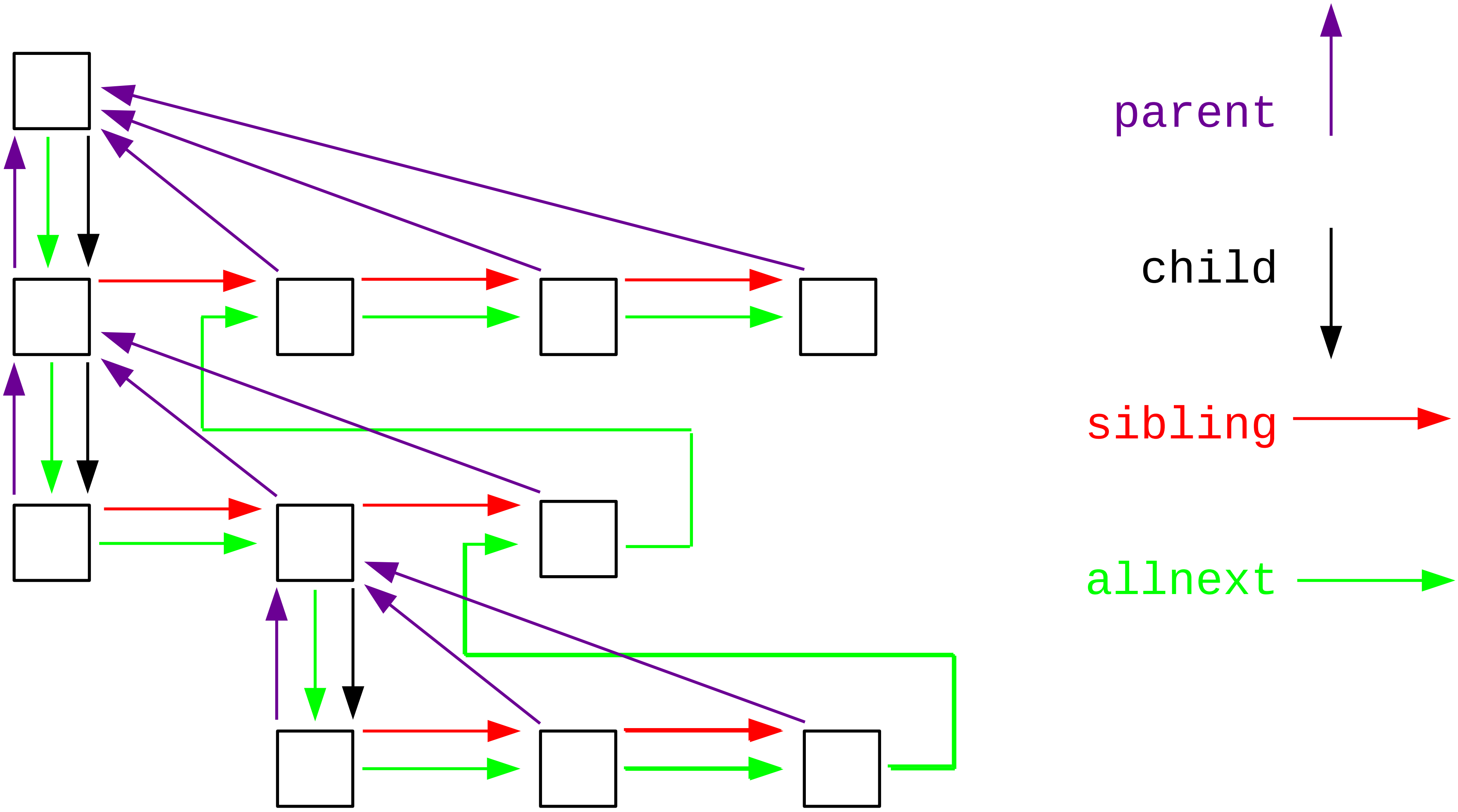
Expanded format

`tree of struct device_node`

parent pointer

Expanded format

tree of struct device_node



parent

child

sibling

allnext

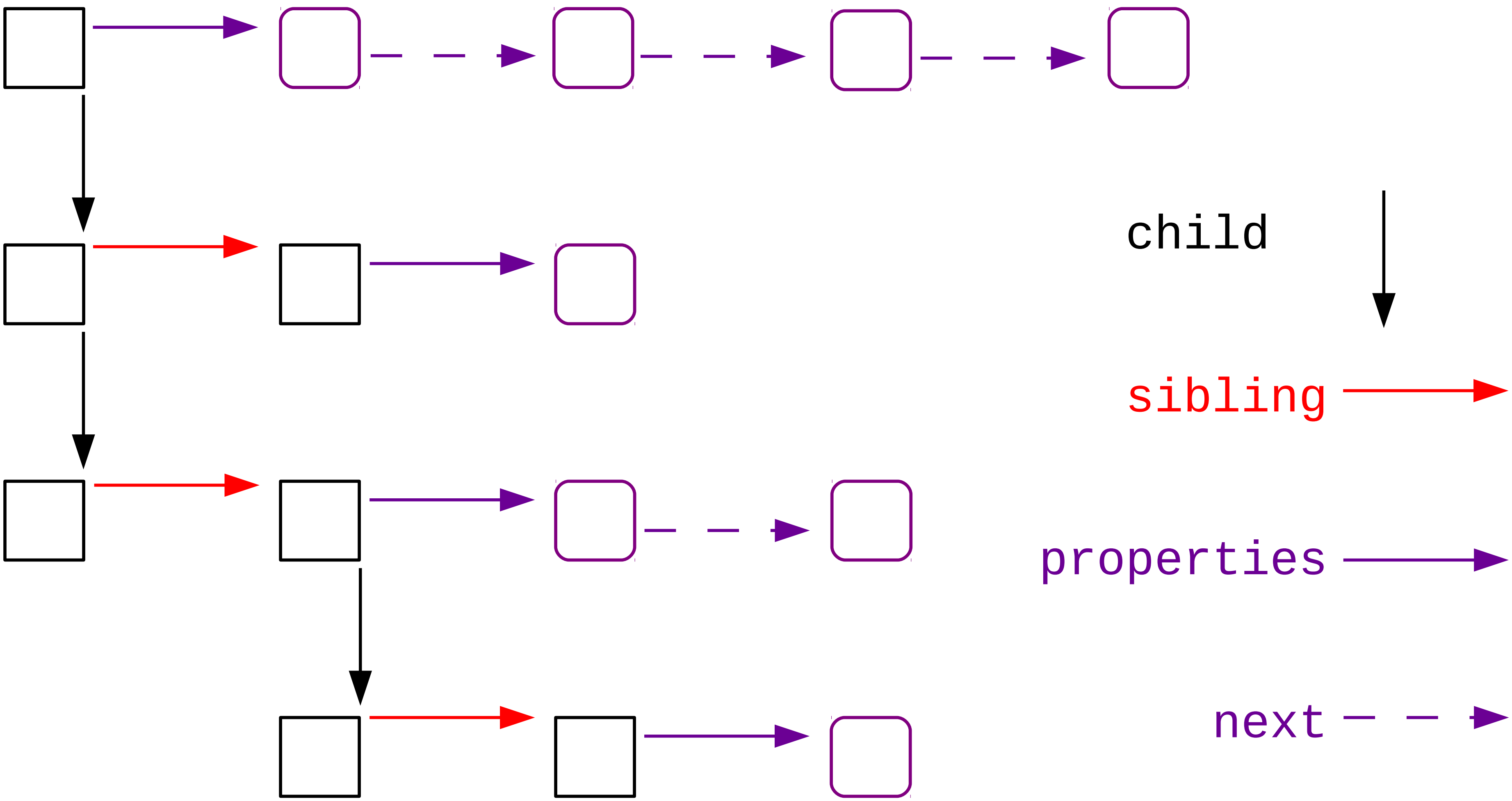
Expanded format `tree of struct device_node`

properties pointer

```
struct property {
   char    *name;
   int     length;
   void    *value;
   struct property *next;
   unsigned long _flags;
   unsigned int unique_id;
   struct bin_attribute attr;
};
```

Expanded format

tree of struct device_node



Chapter 2

Matching boot customization options to the device tree

Kernel boot

Linux kernel - machine_desc

A struct machine_desc describes boot customizations for a specific device tree

A struct machine_desc may be used for several different device trees

Linux kernel - machine_desc

A struct machine_desc describes boot customizations for a specific device tree

A struct machine_desc may be used for several different device trees

machine_desc

```
struct machine_desc {
   unsigned int          nr;          /* architecture */
   const char            *name;       /* architecture */
   unsigned long         atag_offset;
   char  *dt_compat;                  /* 'compatible' strings *

   unsigned int          nr_irqs;
   phys_addr_t           dma_zone_size;
   ...
   enum reboot_mode      reboot_mode;
   unsigned              l2c_aux_val;  /* L2 cache */
   unsigned              l2c_aux_mask; /* L2 cache */
   ...
   struct smp_operations *smp;
   ...
   void                  (*init_XXX)();
   ...
```

machine_desc boot hooks

```
struct machine_desc {
   ...
   void  (*l2c_write_sec)();
   bool  (*smp_init)();
   void  (*fixup)();
   void  (*dt_fixup)();
   void  (*init_meminfo)();
   void  (*reserve)();
   void  (*map_io)();
   void  (*init_early)();
   void  (*init_irq)();
   void  (*init_time)();
   void  (*init_machine)();
   void  (*init_late)();
   void  (*handle_irq)();
   void  (*restart)();
```

machine_desc runtime hooks

```
struct machine_desc {
   ...
   void   (*l2c_write_sec)();
   ...
   void   (*handle_irq)();
   void   (*restart)();
```

machine_desc - populating array

```
#define DT_MACHINE_START(_name, _namestr)             \
static const struct machine_desc __mach_desc_##_name  \
 __used                                               \
 __attribute__((__section__(".arch.info.init"))) = {  \
   .nr                = ~0,                           \
   .name              = _namestr,


#define MACHINE_END                             \
};
```

machine_desc - populating array

```
#define DT_MACHINE_START(_name, _namestr)             \
static const struct machine_desc __mach_desc_##_name  \
 __used                                               \
 __attribute__((__section__(".arch.info.init"))) = {  \
   .nr                 = ~0,                          \
   .name               = _namestr,


#define MACHINE_END                             \
};
```

machine_desc - populating array

Minimalist Example

```
static const char * const qcom_dt_match[] __initconst = {
   "qcom,apq8074-dragonboard",
   "qcom,apq8084",
   "qcom,msm8660-surf",
   NULL
};


DT_MACHINE_START(QCOM_DT, "Qualcomm (Flattened Device Tree)")
   .dt_compat = qcom_dt_match,
MACHINE_END
```

machine_desc - populating array

```
#define DT_MACHINE_START(_name, _namestr)             \
static const struct machine_desc __mach_desc_##_name  \
 __attribute__((__section__(".arch.info.init"))) = {  \
   .name           = _namestr,
```

```
DT_MACHINE_START(QCOM_DT, "Qualcomm (Flattened Device Tree)")
    .dt_compat = qcom_dt_match,
MACHINE_END
```

```
$ cat /proc/cpuinfo | grep Hardware
Hardware        : Qualcomm (Flattened Device Tree)
```

System.map:

```
       c0905c5c T __arch_info_begin
       c0905c5c t __mach_desc_QCOM_DT
       c0905db4 T __arch_info_end
```

machine_desc - populating array

multiple machine_desc example

```
DT_MACHINE_START(QCOM_DT, "Qualcomm (Flattened Device Tree)")
   .dt_compat = qcom_dt_match,
MACHINE_END

#ifdef CONFIG_ARCH_MULTIPLATFORM
     DT_MACHINE_START(GENERIC_DT, "Generic DT based system")
     MACHINE_END
#endif
```

machine_desc - populating array

multiple machine_desc example

```
DT_MACHINE_START(QCOM_DT, "Qualcomm (Flattened Device Tree)")
   .dt_compat = qcom_dt_match,
MACHINE_END

DT_MACHINE_START(GENERIC_DT, "Generic DT based system")
MACHINE_END
```

Result in System.map from linker magic:

```
c0905c5c T __arch_info_begin
c0905c5c t __mach_desc_GENERIC_DT.18665
c0905cb4 t __mach_desc_QCOM_DT
c0905d0c T __arch_info_end
```

machine_desc - best match

Selecting the machine_desc that best matches the Device Tree loaded by the bootloader

machine_desc - best match

The struct machine_desc with

- a matching compatible
- that is the leftmost in the Device Tree root node compatible list

best match - Device Tree

First DT source example was not complex enough so here is a more complex example

```
/ {
  model = "TI Zoom3";
  compatible = "ti,omap3-zoom3", "ti,omap36xx", "ti,omap3";
};
```

best match - machine_desc array

```
DT_MACHINE_START(OMAP3_DT, "Generic OMAP3 (Flattened Device Tre
        .init_early     = omap3430_init_early,
        .dt_compat      = omap3_boards_compat,
MACHINE_END
DT_MACHINE_START(OMAP36XX_DT, "Generic OMAP36xx (Flattened Devi
        .init_early     = omap3630_init_early,
        .dt_compat      = omap36xx_boards_compat,
MACHINE_END

static const char *omap3_boards_compat[] __initconst = {
        "ti,omap3430",
        "ti,omap3",
        NULL,
};
static const char *omap36xx_boards_compat[] __initconst = {
        "ti,omap36xx",
        NULL,
};
```

best match - machine_desc array

```
/ {
  model = "TI Zoom3";
  compatible = "ti,omap3-zoom3", "ti,omap36xx", "ti,omap3";
};
```

```
static const char *omap3_boards_compat[] __initconst = {
        "ti,omap3430",
        "ti,omap3",
        NULL,
};
static const char *omap36xx_boards_compat[] __initconst = {
        "ti,omap36xx",
        NULL,
};
```

best match - machine_desc array

```
/ {
  model = "TI Zoom3";
  compatible = "ti,omap3-zoom3", "ti,omap36xx", "ti,omap3";
};

DT_MACHINE_START(OMAP36XX_DT, "Generic OMAP36xx (Flattened Devi
        .init_early     = omap3630_init_early,
        .dt_compat      = omap36xx_boards_compat,
MACHINE_END
```

```
static const char *omap36xx_boards_compat[] __initconst = {
        "ti,omap36xx",
        NULL,
};
```

machine_desc - best match

The struct machine_desc with
- a matching compatible
- that is the leftmost in the Device Tree
  root node compatible list

.dts - ranking examples

Why provide options for ranking?

```
/ {
  model = "TI Zoom3";
  compatible = "ti,omap3-zoom3", "ti,omap36xx", "ti,omap3";
};
```

Allows a newer kernel to customize the boot for specific classes or models of older hardware with a baked in device tree.

.dts - ranking examples

Why provide options for ranking?

```
/ {
  model = "TI Zoom3";
  compatible = "ti,omap3-zoom3", "ti,omap36xx", "ti,omap3";
};
```

Allows a newer kernel to customize the boot for specific classes or models of older hardware with a baked in device tree.

Not intended to allow shipping half baked device tree instances.

My pseudocode conventions

- Will obviously fail to compile
- Will usually not show function arguments
- Each level of indention indicated either
  - body of control statement (if, while, etc)
  - entry into function listed on previous line
- Double indentation indicates an intervening level of function call is not shown
- Will often leave out many details or fabricate specific details in the interest of simplicity

machine_desc boot hooks

```
struct machine_desc {
   ...
   void  (*l2c_write_sec)();
   bool  (*smp_init)();
   void  (*fixup)();
   void  (*dt_fixup)();
   void  (*init_meminfo)();
   void  (*reserve)();
   void  (*map_io)();
   void  (*init_early)();
   void  (*init_irq)();
   void  (*init_time)();
   void  (*init_machine)();
   void  (*init_late)();
   void  (*handle_irq)();
   void  (*restart)();
```

machine_desc runtime hooks

```
struct machine_desc {
    ...
    void    (*l2c_write_sec)();
    ...
    void    (*handle_irq)();
    void    (*restart)();
```

machine_desc - hooks example

```
static const char * const tegra_dt_board_compat[] = {
   "nvidia,tegra124",
   "nvidia,tegra114",
   "nvidia,tegra30",
   "nvidia,tegra20",
   NULL
};

DT_MACHINE_START(TEGRA_DT, "NVIDIA Tegra SoC (Flattened Device
   .l2c_aux_val    = 0x3c400001,
   .l2c_aux_mask   = 0xc20fc3fe,
   .smp            = smp_ops(tegra_smp_ops),
   .map_io         = tegra_map_common_io,
   .init_early     = tegra_init_early,
   .init_irq       = tegra_dt_init_irq,
   .init_machine   = tegra_dt_init,
   .init_late      = tegra_dt_init_late,
   .restart        = tegra_pmc_restart,
   .dt_compat      = tegra_dt_board_compat,
MACHINE_END
```

machine_desc hooks (all)

```
start_kernel()
   pr_notice("%s", linux_banner)
   setup_arch()
      mdesc = setup_machine_fdt(__atags_pointer)
         mdesc = of_flat_dt_match_machine()
         /* sometimes firmware provides buggy data */
            mdesc->dt_fixup()
      early_paging_init()
            mdesc->init_meminfo()
      arm_memblock_init()
            mdesc->reserve()
      paging_init()
         devicemaps_init()
               mdesc->map_io()
      ...
         arm_pm_restart = mdesc->restart
      unflatten_device_tree()   <===============
            if (mdesc->smp_init())
      ...
         handle_arch_irq = mdesc->handle_irq
      ...
         mdesc->init_early()
   pr_notice("Kernel command line: %s\n", ...)
   init_IRQ()
         machine_desc->init_irq()
      outer_cache.write_sec = machine_desc->l2c_write_sec
   time_init()
         machine_desc->init_time()
   rest_init()
      kernel_thread(kernel_init, ...)
         kernel_init()
                  do_initcalls()
                     customize_machine()
                           machine_desc->init_machine()
                     // device probing, driver binding
                     init_machine_late()
                           machine_desc->init_late()
```

machine_desc hooks (0 of 3)

```
start_kernel()
   pr_notice("%s", linux_banner)
   setup_arch()
      mdesc = setup_machine_fdt(__atags_pointer)
         mdesc = of_flat_dt_match_machine()

            /*
             * Iterate through machine match
             * tables to find the best match for
             * the machine compatible string in
             * the FDT.
```

machine_desc hooks (1 of 3)

```
start_kernel()
   pr_notice("%s", linux_banner)
   setup_arch()
      mdesc = setup_machine_fdt(__atags_pointer)
         mdesc = of_flat_dt_match_machine()
         /* sometimes firmware provides buggy data *
            mdesc->dt_fixup()
      early_paging_init()
            mdesc->init_meminfo()
      arm_memblock_init()
            mdesc->reserve()
      paging_init()
         devicemaps_init()
               mdesc->map_io()
      ...
         arm_pm_restart = mdesc->restart
      unflatten_device_tree()   <===============
```

machine_desc hooks (2 of 3)

```
   unflatten_device_tree()   <===============
         if (mdesc->smp_init())
   ...
      handle_arch_irq = mdesc->handle_irq
   ...
      mdesc->init_early()
   /* end of setup_arch() */
pr_notice("Kernel command line: %s\n", ...)
init_IRQ()
      machine_desc->init_irq()
   outer_cache.write_sec =
                    machine_desc->l2c_write_sec
time_init()
      machine_desc->init_time()
```

machine_desc hooks (3 of 3)

```
rest_init()
   kernel_thread(kernel_init, ...)
      kernel_init()
              do_initcalls()
                customize_machine()
                     machine_desc->init_machine()
                // device probing, driver binding
                init_machine_late()
                     machine_desc->init_late()
```

machine_desc magic values

Bug or Feature?

Values that affect the Device Tree boot process

machine_desc magic values

Bug or Feature?

```
struct machine_desc {
    ...
    unsigned                   l2c_aux_val;  /* L2 cache */
    unsigned                   l2c_aux_mask; /* L2 cache */
```

A magic value is required to enable check for compatible L2 nodes in the device tree:

```
  .l2c_aux_val     = 0,    // default value
  .l2c_aux_mask    = ~0,   // not default value
```

machine_desc magic values

```
struct machine_desc {
   ...
   unsigned              l2c_aux_val;  /* L2 cache */
   unsigned              l2c_aux_mask; /* L2 cache */
```

Examples:

```
DT_MACHINE_START(ROCKCHIP_DT, "Rockchip Cortex-A9 (Device Tree)
        .l2c_aux_val    = 0,
        .l2c_aux_mask   = ~0,
        .dt_compat      = rockchip_board_dt_compat,

DT_MACHINE_START(TEGRA_DT, "NVIDIA Tegra SoC (Flattened Device
        .l2c_aux_val    = 0x3c400001,
        .l2c_aux_mask   = 0xc20fc3fe,
        …
        .dt_compat      = tegra_dt_board_compat,
```

machine_desc magic values

```
init_irq()
  if (... && (l2c_aux_mask || l2c_aux_val))
    l2x0_of_init(l2c_aux_val, l2c_aux_mask)
      np = of_find_matching_node(NULL, l2x0_ids)
      data = of_match_node(l2x0_ids, )->data
        if (…)
          data->of_parse(np, &aux_val, &aux_mask)
            // example of_parse()
            val  = AAA
            mask = BBB
            over_ride = of_property_read_bool(, "wt-override")
            if (over_ride)
              val  |= CCC
              mask |= DDD
            *aux_val  &= mask
            *aux_mask |= val
            *aux_mask &= ~mask
      __l2c_init(, aux_val, aux_mask, )
        /* aux_mask: bits we preserve, aux_val: bits we set
```

machine_desc magic values

```
init_irq()
  if (... && (l2c_aux_mask || l2c_aux_val))
    l2x0_of_init(l2c_aux_val, l2c_aux_mask)
      np = of_find_matching_node(NULL, l2x0_ids)
      data = of_match_node(l2x0_ids, )->data
        if (...)
          data->of_parse(np, &aux_val, &aux_mask)
            // example of_parse()
            val  = AAA
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            *aux_val  &= mask
            *aux_mask |= val
            *aux_mask &= ~mask
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        /* aux_mask: bits we preserve, aux_val: bits we set
```

machine_desc magic values

```
init_irq()
  if (... && (l2c_aux_mask || l2c_aux_val))
    l2x0_of_init(l2c_aux_val, l2c_aux_mask)
      np = of_find_matching_node(NULL, l2x0_ids)
      data = of_match_node(l2x0_ids, )->data
        if (…)
          data->of_parse(np, &aux_val, &aux_mask)
            // example of_parse()
            val  = AAA
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            over_ride = of_property_read_bool(, "wt-override")
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              val  |= CCC
              mask |= DDD
            *aux_val  &= mask
            *aux_mask |= val
            *aux_mask &= ~mask
      __l2c_init(, aux_val, aux_mask, )
        /* aux_mask: bits we preserve, aux_val: bits we set
```

Takeaway

The struct machine_desc with the best match for the Device Tree root node compatible string is chosen

The values in the struct machine_desc can alter the boot process

Minimize use of machine_desc hooks

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The struct machine_desc with the best match for the Device Tree root node compatible string is chosen

The values in the struct machine_desc can alter the boot process

Minimize use of machine_desc hooks

Chapter 3

More kernel boot

- Creating devices
- Matching devices and drivers

Chapter 3.1

More kernel boot

- **Creating devices**
- Matching devices and drivers

Initcalls

Previous pseudo-code of boot is oversimplified, but I will continue with this deception for a few more slides:

```
do_initcalls()
   customize_machine()
      if (machine_desc->init_machine)
         machine_desc->init_machine()
      else
         of_platform_populate()
   // driver binding
   init_machine_late()
      machine_desc->init_late()
```

Initcalls

But one clue about the deception - initcalls occur in this order:

```
char *initcall_level_names[] = {
     "early",
     "core",
     "postcore",
     "arch",
     "subsys",
     "fs",
     "device",
     "late",
}
```

Initcall - of_platform_populate()

```
if (machine_desc->init_machine)
   machine_desc->init_machine()
      /* this function will call
       * of_platform_populate() */
else
   of_platform_populate()
```

Watch out for board specific data passed in of_platform_populate(, lookup,,,)

See the struct of_dev_auxdata header comment in include/linux/of_platform.h regarding device names and providing platform data

initcall - of_platform_populate()

```
of_platform_populate(, NULL,,,)
   for each child of DT root node
      rc = of_platform_bus_create(child, matches, lookup, parent, true)
         if (node has no 'compatible' property)
            return
         auxdata = lookup[X], where:
            #  lookup[X]->compatible matches node compatible property
            #  lookup[X]->phys_addr  matches node resource 0 start
         if (auxdata)
            bus_id = auxdata->name
            platform_data = auxdata->platform_data
         dev = of_platform_device_create_pdata(, bus_id, platform_data, )
            dev = of_device_alloc(np, bus_id, parent)
            dev->dev.bus = &platform_bus_type
            dev->dev.platform_data = platform_data
            of_device_add(dev)
                  bus_probe_device()
                     ret = bus_for_each_drv(,, __device_attach)
                           error = __device_attach()
                              if (!driver_match_device()) return 0
                              return driver_probe_device()
         if (node 'compatible' property != "simple-bus")
            return 0
         for_each_child_of_node(bus, child)
            rc = of_platform_bus_create()
            if (rc) break
      if (rc) break
```

initcall - of_platform_populate()

```
of_platform_populate(, NULL,,,)   /* lookup is NULL */
   for each child of DT root node
      rc = of_platform_bus_create(child, )
         if (node has no 'compatible' property)
            return

         << create platform device for node >>
         << try to bind a driver to device >>

         if (node 'compatible' property != "simple-bus")
            return 0
         for_each_child_of_node(bus, child)
            rc = of_platform_bus_create(child, )
            if (rc) break
      if (rc) break
```

```
<< create platform device for node >>
<< try to bind a driver to device >>

auxdata = lookup[X], with matches:
   lookup[X]->compatible == node 'compatible' property
   lookup[X]->phys_addr  == node resource 0 start
if (auxdata)
   bus_id = auxdata->name
   platform_data = auxdata->platform_data
dev = of_platform_device_create_pdata(, bus_id,
                                        platform_data,)
   dev = of_device_alloc(, bus_id,)
   dev->dev.bus = &platform_bus_type
   dev->dev.platform_data = platform_data
   of_device_add(dev)
         bus_probe_device()
            ret = bus_for_each_drv(,, __device_attach)
                  error = __device_attach()
                     if (!driver_match_device())
                        return 0
                     return driver_probe_device()
```

initcall - of_platform_populate()

platform device created for

- children of root node
- recursively for deeper nodes if 'compatible' property == “simple-bus”

platform device not created if

- node has no 'compatible' property

initcall - of_platform_populate()

platform device created for

- children of root node
- recursively for deeper nodes if 'compatible' property == “simple-bus”

platform device not created if

- node has no 'compatible' property

initcall - of_platform_populate()

auxdata may affect how the platform device was created

initcall - of_platform_populate()

auxdata may affect how the platform device was created

initcall - of_platform_populate()

Drivers may be bound to the devices during
platform device creation if driver registered
at an earlier initcall level

- the driver called platform_driver_register()
  from a core_initcall() or a postcore_initcall()
- the driver called platform_driver_register()
  from an arch_initcall() that was called before
  of_platform_populate()

initcall - of_platform_populate()

Drivers may be bound to the devices during platform device creation if driver registered at an earlier initcall level

- the driver called platform_driver_register() from a core_initcall() or a postcore_initcall()
- the driver called platform_driver_register() from an arch_initcall() that was called before of_platform_populate()

Creating other devices

Devices that are not platform devices were not created by of_platform_populate().

These devices are typically non-discoverable devices sitting on more remote busses.
For example:

- i2c
- SoC specific busses

Creating other devices

Devices that are not platform devices were not created by of_platform_populate().

These devices are typically created by the bus driver probe function

Creating other devices

Devices that are not platform devices were not created by of_platform_populate().

These devices are typically created by the bus driver probe function

Chapter 3.2

More kernel boot

- Creating devices
- **Matching devices and drivers**

initcall - // driver binding

```
platform_driver_register()
      driver_register()
                     while (dev = iterate over devices on the platform_bus)
                           if (!driver_match_device()) return 0
                           if (dev->driver) return 0
                           driver_probe_device()
                              really_probe(dev, drv)
                                 ret = pinctrl_bind_pins(dev)
                                 if (ret)
                                    goto probe_failed
                                 if (dev->bus->probe)
                                    ret = dev->bus->probe(dev)
                                    if (ret) goto probe_failed
                                 else if (drv->probe)
                                    ret = drv->probe(dev)
                                    if (ret) goto probe_failed
                                 driver_bound(dev)
                                    driver_deferred_probe_trigger()
                                    if (dev->bus)
                                       blocking_notifier_call_chain()
```

initcall - // driver binding

Reformatting the previous slide to make it more readable (see next slide)

initcall - // driver binding

```
platform_driver_register()
   while (dev = iterate over devices on platform_bus)
      if (!driver_match_device()) return 0
      if (dev->driver) return 0
      driver_probe_device()
         really_probe(dev, drv)
            ret = pinctrl_bind_pins(dev)
            if (ret)
               goto probe_failed
            if (dev->bus->probe)
               ret = dev->bus->probe(dev)
               if (ret) goto probe_failed
            else if (drv->probe)
               ret = drv->probe(dev)
               if (ret) goto probe_failed
            driver_bound(dev)
               driver_deferred_probe_trigger()
               if (...) blocking_notifier_call_chain()
```

Non-platform devices

When a bus controller driver probe function creates the devices on its bus, the device creation will result in the device probe function being called if the device driver has already been registered.

Note the potential interleaving between device creation and driver binding

Non-platform devices

When a bus controller driver probe function creates the devices on its bus, the device creation will result in the device probe function being called if the device driver has already been registered.

Note the potential interleaving between device creation and driver binding

Getting side-tracked

Some deeper understanding of initcalls will be required to be able to explain driver_deferred_probe_trigger()

Initcalls

Previous pseudo-code is oversimplified:

```
do_initcalls()
   customize_machine()
      if (machine_desc->init_machine)
         machine_desc->init_machine()
      else
         of_platform_populate()
   // device probing, driver binding
   init_machine_late()
      machine_desc->init_late()
```

Initcalls - actual implementation

```
do_initcalls()
   for (level = 0; level < ...; level++)
      do_initcall_level(level)
         for (fn = ...; fn < ...; fn++)
            do_one_initcall(*fn)
               ret = rn()
```

Initcalls

```
static initcall_t *initcall_levels[] = {
   __initcall0_start,
   __initcall1_start,
   __initcall2_start,
   __initcall3_start,
   __initcall4_start,
   __initcall5_start,
   __initcall6_start,
   __initcall7_start,
   __initcall_end,
}
```

Initcalls - order of execution

Pointers to functions for each init level are grouped together by linker scripts

Example ${KBUILD_OUTPUT}/System.map:

```
c0910edc T __initcall0_start
c0910edc t __initcall_ipc_ns_init0
c0910ee0 t __initcall_init_mmap_min_addr0
c0910ee4 t __initcall_net_ns_init0
c0910ee8 T __initcall1_start
...
c0910f50 T __initcall2_start
...
c0910f84 T __initcall3_start
...
...
c0911310 T __initcall7_start
...
c0911368 T __con_initcall_start
...
c0911368 T __initcall_end
```

Initcalls - order of execution

The order of initcall functions within an init level should be considered to be non-deterministic.

Initcalls - order of execution

The order of initcall functions within an init level should be considered to be non-deterministic

- Whether a probe will defer may be based on when hardware becomes available
- Initcalls are allowed to start asynchronous activity
- Option to scramble the order of device_initcalls has been proposed to increase test coverage of handling probe defer dependencies

Initcalls - order of execution

If you suspect that an initcall ordering is resulting in interdependent drivers failing to probe, then ordering can be determined by:

- add 'initcall_debug' to the kernel command line to print each initcall to console as it is called
- examining the order in System.map (does not account for deferred probes)

Initcalls - order of execution

If you suspect that an initcall ordering is resulting in interdependent drivers failing to probe, then the solution is **NOT** to play games to re-order them.

The solution is to use deferred probe.

Deferred Probe - driver example

```
serial_omap_probe()
   uartirq = irq_of_parse_and_map()
   if (!uartirq)
      return -EPROBE_DEFER
```

A required resource is not yet available, so
the driver needs to tell the probe framework
to defer the probe until the resource is available

Deferred Probe - probe framework

```
really_probe()
   if (dev->bus->probe)
      ret = dev->bus->probe()
      if (ret) goto probe_failed
   driver_deferred_probe_trigger()
   goto done
probe_failed:
   if (ret == -EPROBE_DEFER)
      dev_info("Driver %s requests probe”
               “deferral\n", drv->name)
      driver_deferred_probe_add(dev);
      /* trigger occur while probing? */
      if (local_trigger_count != ...)
         driver_deferred_probe_trigger()
```

Deferred Probe - probe framework

```
really_probe()
   if (dev->bus->probe)
      ret = dev->bus->probe()
      if (ret) goto probe_failed
   driver_deferred_probe_trigger()
   goto done
probe_failed:
   if (ret == -EPROBE_DEFER)
      dev_info("Driver %s requests probe”
               “deferral\n", drv->name)
      driver_deferred_probe_add(dev);
      /* trigger occur while probing? */
      if (local_trigger_count != ...)
         driver_deferred_probe_trigger()
```

Deferred Probe - probe framework

```
really_probe()
   if (dev->bus->probe)
      ret = dev->bus->probe()
      if (ret) goto probe_failed
   driver_deferred_probe_trigger()
   goto done
probe_failed:
   if (ret == -EPROBE_DEFER)
      dev_info("Driver %s requests probe”
               “deferral\n", drv->name)
      driver_deferred_probe_add(dev);
      /* trigger occur while probing? */
      if (local_trigger_count != ...)
         driver_deferred_probe_trigger()
```

Deferred Probe - probe framework

```
driver_deferred_probe_trigger()
   /*
    * A successful probe means that all the
    * devices in the pending list should be
    * triggered to be reprobed.  Move all
    * the deferred devices into the active
    * list so they can be retried by the
    * workqueue
    */
```

Deferred Probe - probe framework

`driver_deferred_probe_trigger()`

Called when:

- a driver is bound
- a new device is created
- as a late_initcall: `deferred_probe_initcall()`

The framework does not know if the resource(s) required by a driver are now available. It just blindly retries all of the deferred probes.

Deferred Probe - probe framework

`driver_deferred_probe_trigger()`

Called when:

- a driver is bound
- a new device is created
- as a late_initcall: `deferred_probe_initcall()`

The framework does not know if the resource(s) required by a driver are now available. It just blindly retries all of the deferred probes.

Initcalls - parallelism support

Additional *_sync level added after each other level to allow asynchronous activity to complete before beginning next level

For details:
https://lkml.org/lkml/2006/10/27/157

Initcalls - initcall level #defines

```
core_initcall(fn)           __define_initcall(fn, 1)
core_initcall_sync(fn)      __define_initcall(fn, 1s)
postcore_initcall(fn)       __define_initcall(fn, 2)
postcore_initcall_sync(fn)  __define_initcall(fn, 2s)
arch_initcall(fn)           __define_initcall(fn, 3)
arch_initcall_sync(fn)      __define_initcall(fn, 3s)
subsys_initcall(fn)         __define_initcall(fn, 4)
subsys_initcall_sync(fn)    __define_initcall(fn, 4s)
fs_initcall(fn)             __define_initcall(fn, 5)
fs_initcall_sync(fn)        __define_initcall(fn, 5s)
rootfs_initcall(fn)         __define_initcall(fn, rootfs)
device_initcall(fn)         __define_initcall(fn, 6)
device_initcall_sync(fn)    __define_initcall(fn, 6s)
late_initcall(fn)           __define_initcall(fn, 7)
late_initcall_sync(fn)      __define_initcall(fn, 7s)
```

Initcalls - driver register, device create

what is in the kernel now:

```
“core”      : platform_driver_register()
“postcore” : platform_driver_register()
“subsys”    : platform_driver_register()
“arch”      : customize machine()
                 of_platform_populate()
“device”    : platform_driver_register()
```

Initcalls - driver register, device create

what is likely to be accepted for new code:

```
“arch”      : customize machine()
                 of_platform_populate()

“device”    : platform_driver_register()
```

Chapter 4

Miscellaneous

Some DT issues

Circular dependencies on driver probe

- Use a third driver to resolve the conflict

Devices with multiple compatible strings

- If multiple drivers match one of the values then the first one to probe is bound. The winner is based on the arbitrary initcall order.
- A better result would be for the driver with the most specific compatible to be bound.

The Near Future and Near Past

GIT PULL request for v3.17

Preparation for device tree overlay support
- notifiers moved from before to after change
- batch changes
- notifiers emitted after entire batch applied
- unlocked versions of node and property
  add / remove functions (caller ensures locks)

Enable console on serial ports specified by
/chosen/stdout-path

Data for DT unit tests no longer in the booted dtb
- dynamically loaded before tests
- dynamically unloaded after tests

partial TODO (v3.17 pull request)

=== General structure ===

- Switch from custom lists to (h)list_head for nodes and properties structure
- Remove of_allnodes list and iterate using list of child nodes alone

=== CONFIG_OF_DYNAMIC ===

- Switch to RCU for tree updates and get rid of global spinlock
- Always set ->full_name at of_attach_node() time

v3.18 and beyond

Preparation for device tree overlay support

- Device Tree Dynamic Resolver (at v2)
- more...

Internal data structure implementation changes

Some things not covered

- Memory, IRQs, clocks
- pinctrl
- Devices and busses other than platform devices
- sysfs
- locking and reference counting
- '/chosen' node
- details of matching machine desc to device tree
- dynamic node and property addition / deletion
- smp operations
- device tree self test

Review

- life cycle of device tree data, data structures
  access functions change after blob expansion
- customizing the boot process by machine_desc
  uses best machine_desc match to device tree
- device creation
- driver binding
- ordering dance between device creation and
  various drivers binding, deferred probes

You should now be able to better understand
`Documentation/devicetree/usage-model.txt`

THE   END

Thank you for your attention...

Questions?

How to get a copy of the slides

1) leave a business card with me

2) frank.rowand@sonymobile.com