Continuous Memory Allocator

Allocating big chunks of physically contiguous memory

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Outline

1. Introduction
   - Why physically contiguous memory is needed
   - Solutions to the problem
2. Usage & Integration
   - Using CMA from device drivers
   - Integration with the architecture
   - Private & not so private CMA regions
3. Implementation
   - Page allocator
   - CMA implementation
   - CMA problems and future work

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   - Page allocator
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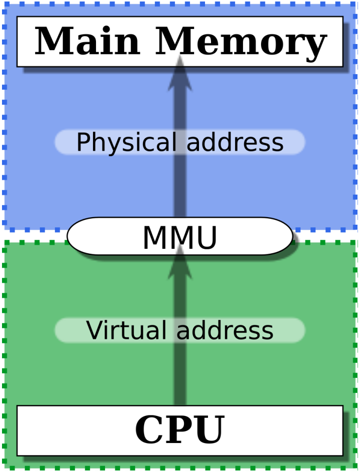
The mighty MMU

- Modern CPUs have MMU.
    - Virtual $\rightarrow$ physical address.
- Virtually contiguous $\not\Rightarrow$ physically contiguous.
- So why bother?



The mighty MMU

- Modern CPUs have MMU.
  - Virtual $\rightarrow$ physical address.
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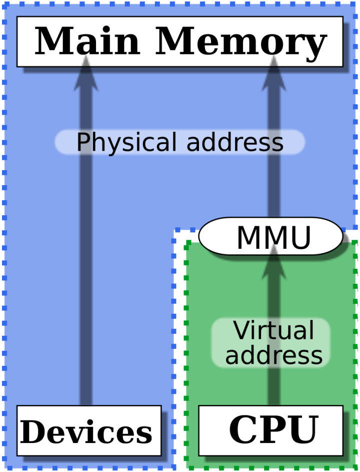
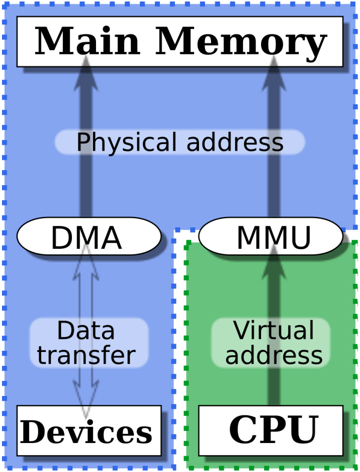
- MMU stands behind CPU.
- There are other chips in the system.
- Some require large buffers.
  - 5-megapixel camera anyone?
- On embedded, there's plenty of those.



The mighty DMA

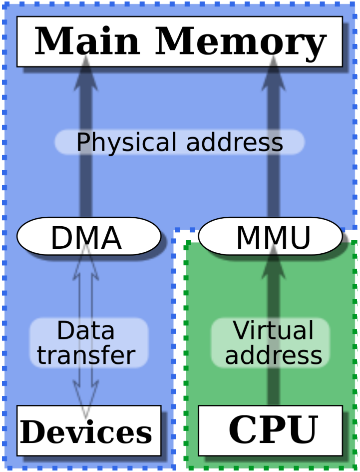
- DMA can do vectored I/O.
- Gathering buffer from scattered parts.
  - Hence also another name: DMA scatter-gather.
- Contiguous for the device $\not\Rightarrow$ physically contiguous.
- So why bother?



The mighty DMA

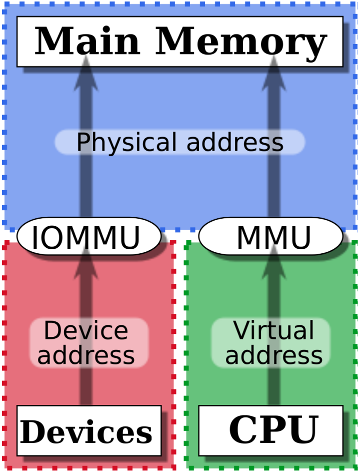
- DMA can do vectored I/O.
- Gathering buffer from scattered parts.
  - Hence also another name: DMA scatter-gather.
- Contiguous for the device $\not\Rightarrow$ physically contiguous.

- DMA may lack vectored I/O support.
- DMA can do linear access only.



The mighty I/O MMU

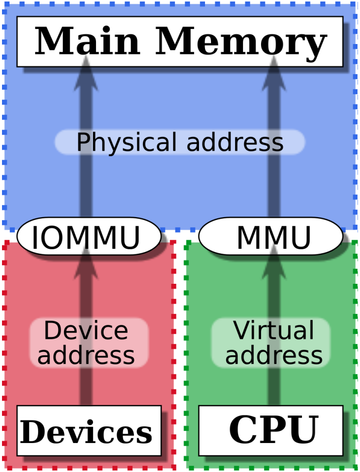
- What about an I/O MMU?
  - Device → physical address.
- Same deal as with CPU's MMU.
- So why bother?



The mighty I/O MMU

- What about an I/O MMU?
  - Device → physical address.
- Same deal as with CPU's MMU.

- I/O MMU is not so common.
- I/O MMU takes time.
- I/O MMU takes power.



Reserve and assign at boot time

- Reserve memory during system boot time.
  - mem parameter.
  - Memblock / bootmem.
- Assign buffers to each device that might need it.
- While device is not being used, memory is wasted.

Reserve and allocate on demand

- Reserve memory during system boot time.
- Provide API for allocating from that reserved pool.
- Less memory is reserved.
- But it's still wasted.

- bigphysarea
- Physical Memory Manager

Reserve but give back

- Reserve memory during system boot time.
- Give it back
  - but set it up so only movable pages can be allocated.
- Provide API for allocating from that reserved pool.
- Migrate pages on allocation.

- Contiguous Memory Allocator

Outline

Using CMA from device drivers

- CMA is integrated with the DMA API.
- If device driver uses the DMA API, nothing needs to be changed.
- In fact, device driver should always use the DMA API and never call CMA directly.

Allocating memory from device driver

Allocation

```c
void *my_dev_alloc_buffer(
    unsigned long size_in_bytes, dma_addr_t *dma_addrp)
{
    void *virt_addr = dma_alloc_coherent(
        my_dev,
        size_in_bytes,
        dma_addrp,
        GFP_KERNEL);
    if (!virt_addr)
        dev_err(my_dev, "Allocation failed.");
    return virt_addr;
}
```

Releasing memory from device driver

Freeing

```
void *my_dev_free_buffer(
      unsigned long size, void *virt, dma_addr_t dma)
{
      dma_free_coherent(my_dev, size, virt, dma);
}
```

Documentation

- Documentation/DMA−API−HOWTO.txt
- Documentation/DMA−API.txt
- Linux Device Drivers, 3rd edition, chapter 15.
  - `http://lwn.net/Kernel/LDD3/`

Integration with the architecture

- CMA needs to be integrated with the architecture.
- Memory needs to be reserved.
- There are early fixups to be done. Or not.
- The DMA API needs to be made aware of CMA.
- And Kconfig needs to be instructed to allow CMA.

Memory reservation

- Memblock must be ready, page allocator must not.
- On ARM, arm_memblock_init() is a good place.
- All one needs to do, is call dma_contiguous_reserve().

Memory reservation

```
void __init dma_contiguous_reserve(
        phys_addr_t limit);
```

`limit` Upper limit of the region (or zero for no limit).

Memory reservation, cont.

Reserving memory on ARM

```
 if (mdesc->reserve)
     mdesc->reserve();

+/*
+ * reserve memory for DMA contigouos allocations,
+ * must come from DMA area inside low memory
+ */
+dma_contiguous_reserve(min(arm_dma_limit, arm_lowmem_limit));
+
 arm_memblock_steal_permitted = false;
 memblock_allow_resize();
 memblock_dump_all();
```

Early fixups

- On ARM
  - cache is not coherent, and
  - having two mappings with different cache-ability gives undefined behaviour.
- Kernel linear mapping uses huge pages.
- So on ARM an "early fixup" is needed.
  - This fixup alters the linear mapping so CMA regions use 4 KiB pages.
- The fixup is defined in dma_contiguous_early_fixup() function
  - which architecture needs to provide
  - with declaration in a asm/dma−contiguous.h header file.

Early fixups, cont.

No need for early fixups

```
#ifndef ASM_DMA_CONTIGUOUS_H
#define ASM_DMA_CONTIGUOUS_H

#ifdef __KERNEL__

#include <linux/types.h>
#include <asm-generic/dma-contiguous.h>

static inline void
dma_contiguous_early_fixup(phys_addr_t base, unsigned long size)
{ /* nop, no need for early fixups */ }

#endif
#endif
```

Integration with DMA API

- The DMA API needs to be modified to use CMA.
- CMA most likely won't be the only one.

Allocating CMA memory

Allocate

```c
struct page *dma_alloc_from_contiguous(
        struct device *dev,
        int count,
        unsigned int align);
```

`dev` Device the allocation is performed on behalf of.

`count` *Number of pages* to allocate. Not number of bytes nor order.

`align` Order which to align to. Limited by Kconfig option.

Returns page that is the first page of count allocated pages. It's not a compound page.

Releasing CMA memory

Release

```
bool dma_release_from_contiguous(
        struct device *dev,
        struct page *pages,
        int count);
```

- **dev** Device the allocation was performed on behalf of.
- **pages** The first of allocated pages. As returned on allocation.
- **count** Number of allocated pages.

Returns true if memory was freed (ie. was managed by CMA) or false otherwise.

Let it compile!

- There's one think that needs to be done in Kconfig.
- Architecture needs to select HAVE_DMA_CONTIGUOUS.
- Without it, CMA won't show up under "Generic Driver Options".
- Architecture may also select CMA to force CMA in.

Default CMA region

- Memory reserved for CMA is called CMA region or CMA context.
- There's one default context devices use.
- So why does dma_alloc_from_contiguous() take device as an argument?
- There may also be per-device or private contexts.

What is a private region for?

- Separate a device into its own pool.
  - May help with fragmentation.
  - For instance big vs small allocations.
  - Several devices may be grouped together.
- Use different contexts for different purposes within the same device.
  - Simulating dual channel memory.
  - Big and small allocations in the same device.

Declaring private regions

Declaring private regions

```
int dma_declare_contiguous(
        struct device *dev,
        unsigned long size,
        phys_addr_t base,
        phys_addr_t limit);
```

- `dev` Device that will use this region.
- `size` *Size in bytes* to allocate. Not pagas nor order.
- `base` Base address of the region (or zero to use anywhere).
- `limit` Upper limit of the region (or zero for no limit).

Returns zero on success, negative error code on failure.

Region shared by several devices

- The API allows to assign a region to a single device.
- What if more than one device is to use the same region.
- It can be easily done via "copying" the context pointer.

Region shared by several devices, cont

Copying CMA context pointer between two devices

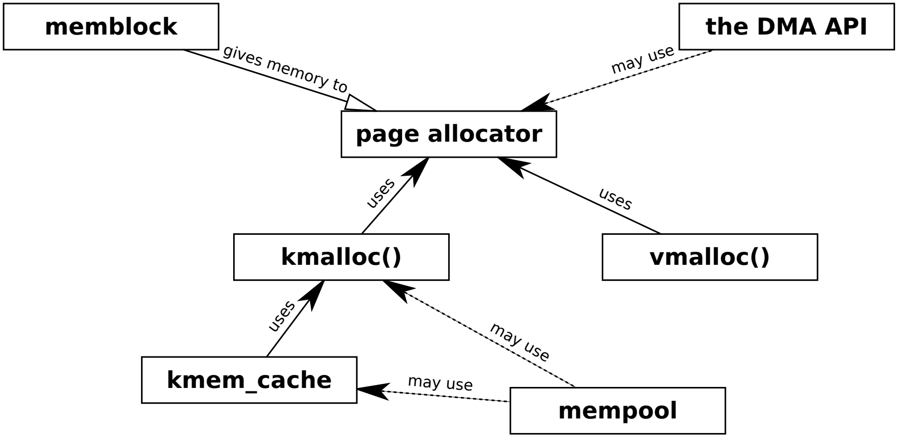
```
static int __init foo_set_up_cma_areas(void) {
	struct cma *cma;
	cma = dev_get_cma_area(device1);
	dev_set_cma_area(device2, cma);
	return 0;
}
postcore_initcall(foo_set_up_cma_areas);
```

Several regions used by the same device

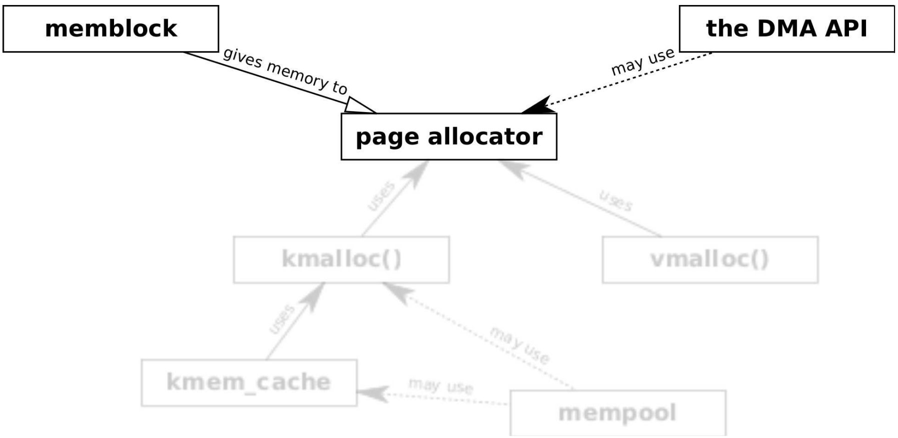
- CMA uses a one-to-many mapping from device structure to CMA region.
- As such, one device can only use one CMA context. . .
- . . . unless it uses more than one device structure.
- That's exactly what S5PV110's MFC does.

Outline

Linux kernel memory allocators

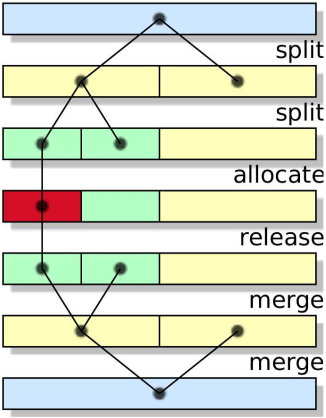


Linux kernel memory allocators

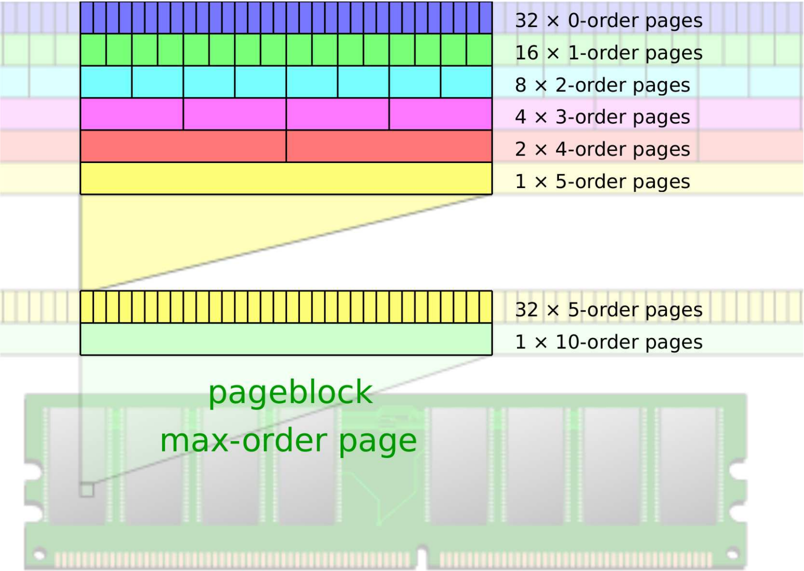


Buddy allocator

- Page allocator uses buddy allocation algorithm.
  - Hence different names: buddy system or buddy allocator.
- Allocations are done in terms of orders.
- User can request order from 0 to 10.
- If best matching page is too large, it's recursively split in half (into two buddies).
- When releasing, page is merged with its buddy (if free).



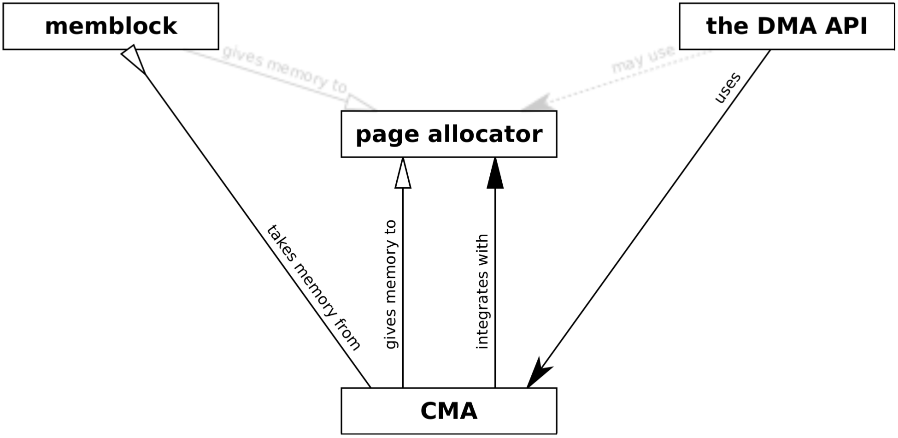
Pages and page blocks, cont



Migrate types

- On allocation, user requests an unmovable, a reclaimable or a movable page.
  - For our purposes, we treat reclaimable as unmovable.
- To try keep pages of the same type together, each free page and each page block has a migrate type assigned.
  - But allocator will use fallback types.
  - And migrate type of a free page and page blocks can change.
- When released, page takes migrate type of pageblock it belongs to.

Interaction of CMA with Linux allocators



CMA migrate type

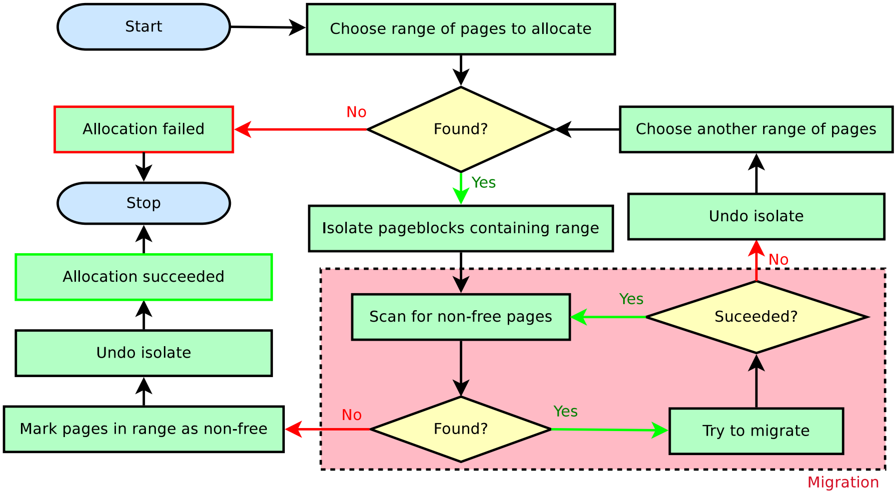
- CMA needs guarantees that large number of contiguous pages can be migrated.
  - 100% guarantee is of course never possible.
- CMA introduced a new migrate type.
  - MIGRATE_CMA
- This migrate type has the following properties:
  - CMA pageblocks never change migrate type.[1]
  - Only movable pages can be allocated from CMA pageblocks.

[1] Other than while CMA is allocating memory from them.

Preparing CMA region

- At the boot time, some of the memory is reserved.
- When page allocator initialises, that memory is released with CMA's migrate type.
- This way, it can be used for movable pages.
  - Unless the memory is allocated to a device driver.
- Each CMA region has a bitmap of "CMA free" pages.
  - "CMA free" page is one that is not allocated for device driver.
  - It may still be allocated as a movable page.

Allocation


Start
Choose range of pages to allocate
Found?
No
Yes
Allocation failed
Stop
Choose another range of pages
Isolate pageblocks containing range
Undo isolate
No
Allocation succeeded
Scan for non-free pages
Yes
Suceeded?
Undo isolate
Found?
No
Yes
Mark pages in range as non-free
Try to migrate
Migration

Migration

- Pages allocated as movable are set up so that they can be migrated.
  - Such pages are only references indirectly.
  - Examples are anonymous process pages and disk cache.
- Roughly speaking, migration consists of:
  1. allocating a new page,
  2. copying contents of the old page to the new page,
  3. updating all places where old page was referred, and
  4. freeing the old page.
- In some cases, content of movable page can simply be discarded.

Problems

- get_user_pages() makes migration impossible.
- ext4 does not support migration of journal pages.
- Some filesystems are not good on migration.

Future work

- Only swap.
- Transcendent memory.
- POSIX_FADV_VOLATILE.

Thank you!

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