

Lecture 03

Digital I/O and Interrupts

CE346 – Microprocessor System Design
Branden Ghen a – Spring 2026

Some slides borrowed from:
Josiah Hester (Northwestern), Prabal Dutta (UC Berkeley)

Administrivia

- Lab on Friday!
 - Frances Searle room 3220
 - See you all there!!
 - Show up on-time. We are going to get started right away
 - None of this 5-10 minutes late nonsense
- Bring a USB-C adapter if you need one
- Remember that you need to attend the section you registered for in CAESAR
 - If you need to switch for a day, ask me for permission in advance on Piazza



Quiz coming soon

- First quiz is next week Tuesday! (April 14)
 - 15-minute quiz, taken in-class on paper
 - Last fifteen minutes of class
 - Bring a pencil
 - No notes, no calculator
- Covers material from the last two weeks, including today. Both lecture and lab are relevant.
- Goals:
 - The quiz is not meant to be difficult. It's meant to keep you involved
 - Do review class material and make sure you actually understand it
- If you have an accommodation, I emailed you earlier today

Today's Goals

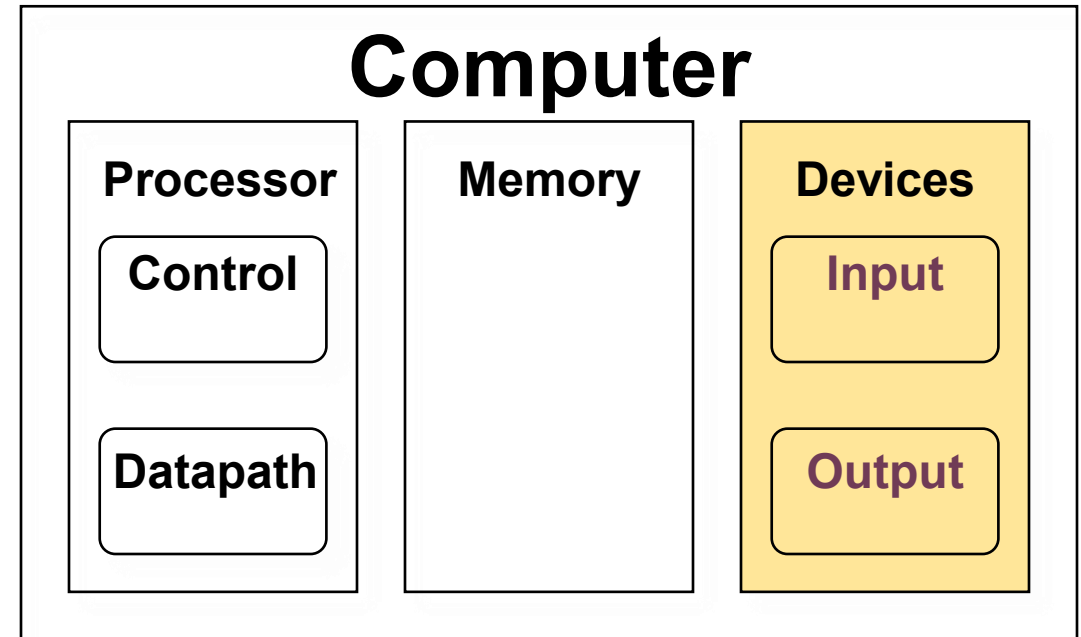
- Two major parts today:
- 1. How does a microcontroller interact with peripherals?
 - Already discussed Memory-Mapped I/O
 - Interrupt and DMA mechanisms today
- 2. How do we interact with digital inputs and outputs?
 - GPIO peripheral for Digital I/O
 - GPIOTE peripheral for interrupts

Outline

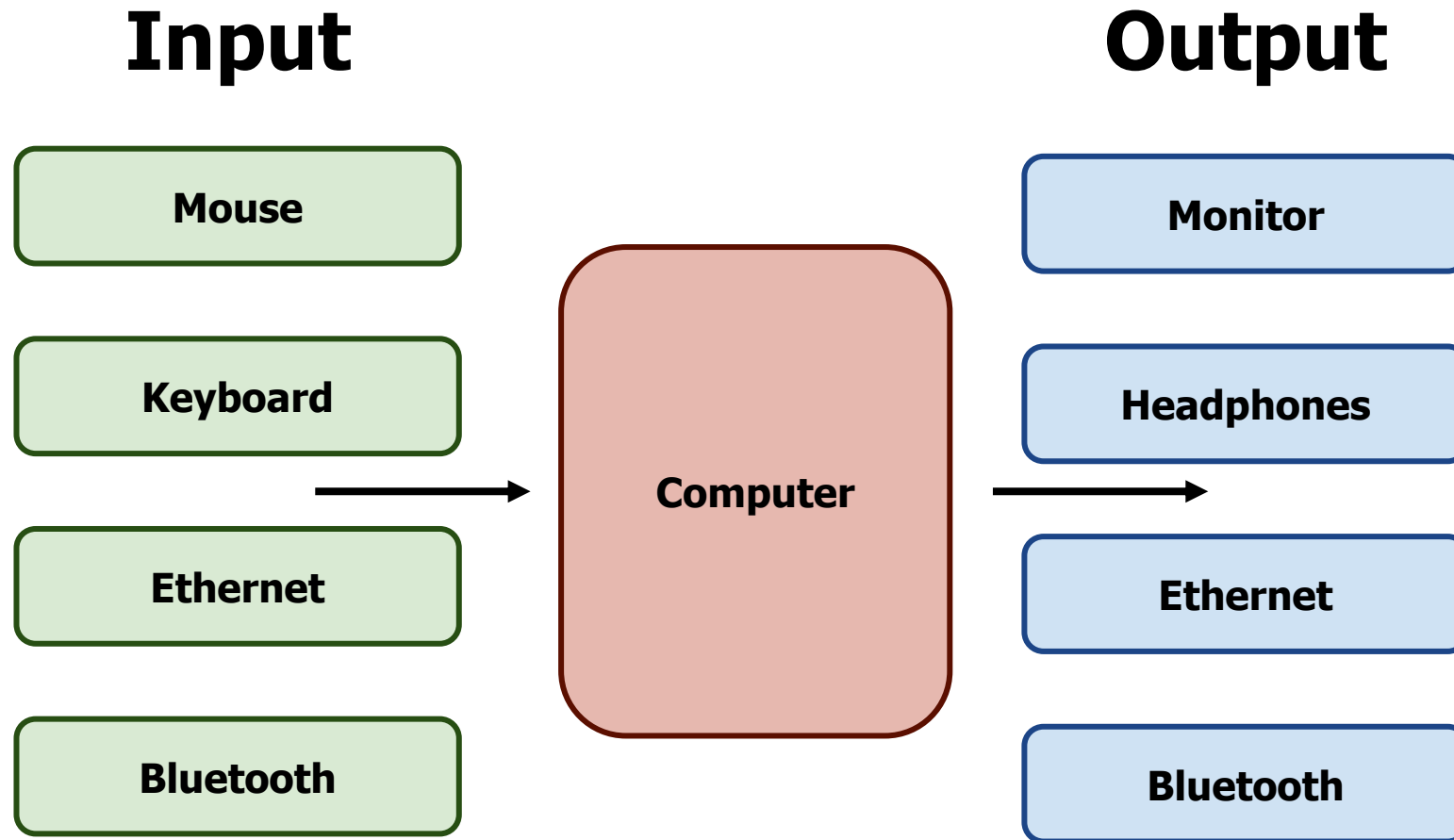
- **I/O Motivation**
- Interrupts
- DMA (Direct Memory Access)
- Controlling digital signals: GPIO peripheral
- Digital input interrupts: GPIOTE peripheral

Devices are the point of computers

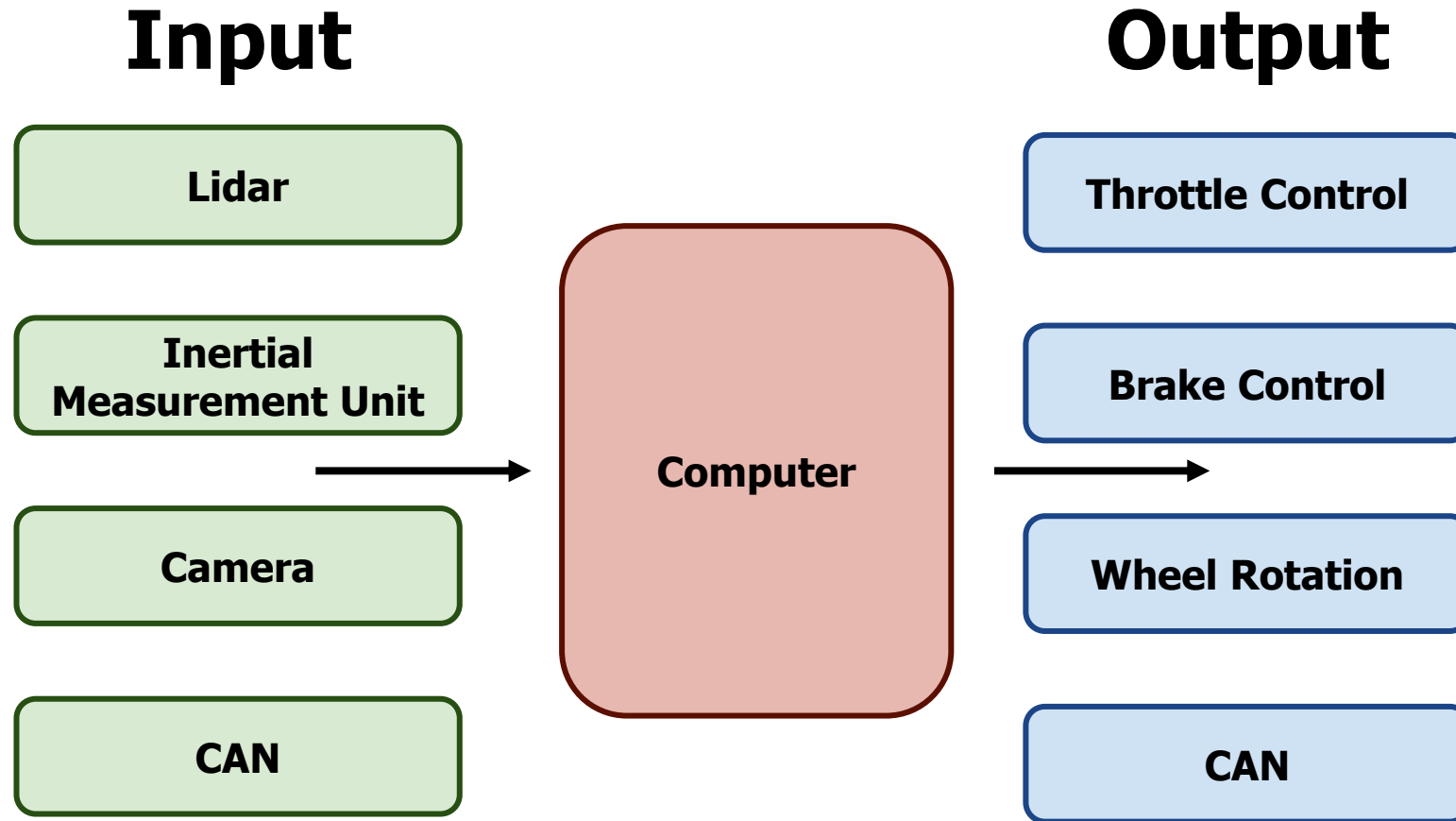
- Traditional systems need to receive input from users and output responses
 - Keyboard/mouse
 - Disk
 - Network
 - Graphics
 - Audio
 - Various USB devices
- Embedded systems have the same requirement, just more types of IO



Devices are core to useful general-purpose computing



Devices are essential to cyber-physical systems too



Device access rates vary by many orders of magnitude

- Rates in bit/sec

- System must be able to handle each of these

- Sometimes needs low overhead
- Sometimes needs to not wait around

Device	Behavior	Partner	Data Rate (Kb/s)
Keyboard	Input	Human	0.2
Mouse	Input	Human	0.4
Microphone	Output	Human	700.0
Bluetooth	Input or Output	Machine	20,000.0
Hard disk drive	Storage	Machine	100,000.0
Wireless network	Input or Output	Machine	300,000.0
Solid state drive	Storage	Machine	500,000.0
Wired LAN network	Input or Output	Machine	1,000,000.0
Graphics display	Output	Human	3,000,000.0

Outline

- From last time: **MMIO Wrap-up**

TEMP on nRF52833 example

- Internal temperature sensor
 - 0.25° C resolution
 - Range equivalent to microcontroller IC (-40° to 105° C)
 - Various configurations for the temperature conversion (ignoring)

Base address	Peripheral	Instance	Description	Configuration
0x4000C000	TEMP	TEMP	Temperature sensor	

Table 110: Instances

Register	Offset	Description
TASKS_START	0x000	Start temperature measurement
TASKS_STOP	0x004	Stop temperature measurement
EVENTS_DATARDY	0x100	Temperature measurement complete, data ready
INTENSET	0x304	Enable interrupt
INTENCLR	0x308	Disable interrupt
TEMP	0x508	Temperature in °C (0.25° steps)

Interacting with the temperature peripheral

TASKS_START

Address offset: 0x000

Start temperature measurement

Bit number	31 30 29 28 27 26 25 24 23 22 21 20 19 18 17 16 15 14 13 12 11 10 9 8 7 6 5 4 3 2 1 0																														
ID	A																														
Reset 0x00000000	0 0																														
ID	R/W	Field	Value ID	Value	Description																										
A	W	TASKS_START			Start temperature measurement																										
			Trigger	1	Trigger task																										

EVENTS_DATARDY

Address offset: 0x100

Temperature measurement complete, data ready

Bit number				31302928 27262524 23222120 19181716 15141312 111098 7654 3210																															
ID				A																															
Reset 0x00000000				0 0																															

Reading a temperature value

TEMP

Address offset: 0x508

Temperature in °C (0.25° steps)

Bit number	31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16	15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
ID	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A	
Reset 0x00000000	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	

ID	R/W	Field	Value ID	Value	Description
A	R	TEMP			Temperature in °C (0.25° steps) Result of temperature measurement. Die temperature in °C, 2's complement format, 0.25 °C steps Decision point: DATARDY

- 32-bit value
- 2's complement (i.e., signed)
- 0.25 °C steps (so 0 = 0°C, 4 = 1°C, etc.)

MMIO addresses for TEMP

- What addresses do we need? (ignore interrupts for now)
 - 0x4000C000 – TASKS_START
 - 0x4000C100 – EVENTS_DATARDY
 - 0x4000C508 - TEMP

Base address	Peripheral	Instance	Description	Configuration
0x4000C000	TEMP	TEMP	Temperature sensor	

Table 110: Instances

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TEMP	0x508	Temperature in °C (0.25° steps)

Example code (temp_mmio app)

```
// loop forever
while (1) {

    // start a measurement
    *(uint32_t*)(0x4000C000) = 1;

    // wait until ready
    volatile uint32_t ready = *(uint32_t*)(0x4000C100);
    while (!ready) {
        ready = *(uint32_t*)(0x4000C100);
    }

    /* WARNING: we can't write the code this way!
     * Without `volatile`, the compiler optimizes out the memory access
     while (!*(uint32_t*)(0x4000C100));
     */

    // read data and print it
    volatile int32_t value = *(int32_t*)(0x4000C508);
    float temperature = ((float)value)/4.0;
    printf("Temperature=%f degrees C\n", temperature);

    nrf_delay_ms(1000);
}
```

Using structs to manage MMIO access

- Writing simple C code and accessing peripherals is great!
- Problems:
 - Need to remember all these long addresses
 - Need to make sure compiler doesn't stop us!
- Solution:
 - Wrap entire access in a struct!
 - Compilers turn it into the same thing in the end anyways

C structs

- Collection of variables placed together in memory

```
typedef struct {  
    uint32_t variable_one;  
    uint32_t variable_two;  
    uint32_t array[2];  
} example_struct_t;
```

- Placement rules - Variables are placed adjacent to each other in memory except:
 - Fields are always aligned to a multiple of their size
 - Padding added to the end to make the total size a multiple of the biggest member
- Microcontrollers can usually ignore these: all registers are the same size!

Temperature peripheral MMIO struct

```
typedef struct {  
    uint32_t TASKS_START;  
    uint32_t TASKS_STOP;  
    uint32_t _unused_A[62];  
    uint32_t EVENTS_DATARDY;  
    uint32_t _unused_B[0x204/4 - 1];  
    uint32_t INTENSET;  
    uint32_t INTENCLR;  
    uint32_t _unused_C[(0x508 - 0x308)/4 - 1];  
    uint32_t TEMP;  
} temp_regs_t;
```

```
volatile temp_regs_t* TEMP_REGS = (temp_regs_t*)(0x4000C000);
```

Register	Offset	Description
TASKS_START	0x000	Start temperature measurement
TASKS_STOP	0x004	Stop temperature measurement
EVENTS_DATARDY	0x100	Temperature measurement complete, data ready
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With increasingly verbose ways to write the size of the “unused” space (any of these will do, but don’t forget the -1)

Temperature peripheral MMIO struct

```
typedef struct {  
    uint32_t TASKS_START;  
    uint32_t TASKS_STOP;  
    uint32_t _unused_A[62];  
    uint32_t EVENTS_DATARDY;  
    uint32_t _unused_B[0x204/4 - 1];  
    uint32_t INTENSET;  
    uint32_t INTENCLR;  
    uint32_t _unused_C[(0x508 - 0x308)/4 - 1];  
    uint32_t TEMP;  
} temp_regs_t;
```

```
volatile temp_regs_t* TEMP_REGS = (temp_regs_t*)(0x4000C000);
```

```
// code to access  
TEMP_REGS->TASKS_START = 1;  
while (TEMP_REGS->EVENTS_DATARDY == 0);  
float temperature = ((float)TEMP_REGS->TEMP)/4.0;
```

Register	Offset	Description
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Accessing the struct accesses the individual memory locations where the registers live!

Using MMIO structs

- Note: structs still don't get you individual bits, they only get you the 32-bit registers themselves
- You'll need to do bit manipulations to get the read/write fields you want
- Bit fields are an option in C that can allow access to individual bits, but are generally not used
 - Implementation-specific details for how they actually work
 - What if you need to change multiple fields simultaneously?

Break + Question

- Are compiled binaries portable to other types of microcontrollers?

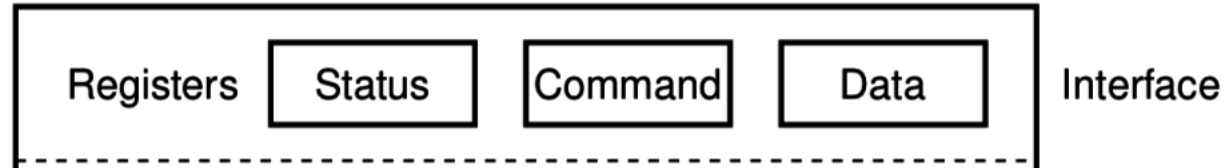
Break + Question

- Are compiled binaries portable to other types of microcontrollers?
 - Definitely not
 - 1) Each microcontroller has its own layout of Flash and RAM, so we might need to put our code in different locations
 - 2) Each microcontroller has its own MMIO addresses and devices
And every device works at least *slightly* differently
 - Can *sometimes* get away with it for microcontrollers in the same family
 - I.e., class code might work on an nRF52840 instead of our nRF52833

Outline

- I/O Motivation
- **Interrupts**
- DMA (Direct Memory Access)
- Controlling digital signals: GPIO peripheral
- Digital input interrupts: GPIOTE peripheral

What do interactions with devices look like?



1. while STATUS==BUSY; Wait
 - (Need to make sure device is ready for a command)
2. Write value(s) to DATA
3. Write command(s) to COMMAND
4. while STATUS==BUSY; Wait
 - (Need to make sure device has completed the request)
5. Read value(s) from Data

This is the “polling” model of I/O.

“Poll” the peripheral in software repeatedly to see if it’s ready yet.

Waiting can be a waste of CPU time

1. **while STATUS==BUSY; Wait**

- (Need to make sure device is ready for a command)

2. Write value(s) to DATA

3. Write command(s) to COMMAND

4. **while STATUS==BUSY; Wait**

- (Need to make sure device has completed the request)

5. Read value(s) from Data

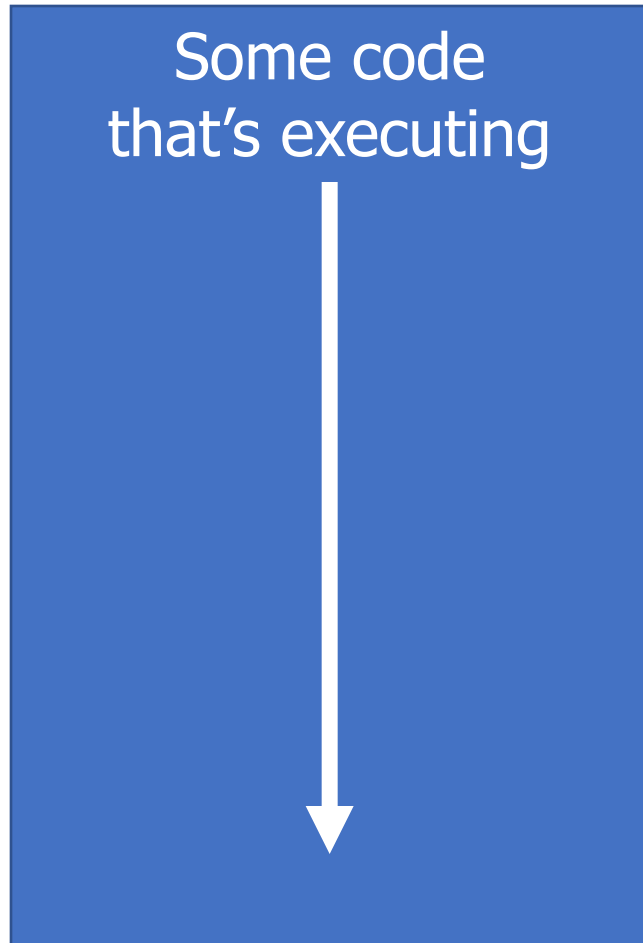
- Problem: imagine a keyboard device

- CPU could be waiting for minutes before data arrives
- Need a way to notify CPU when an event occurs
 - Interrupts!

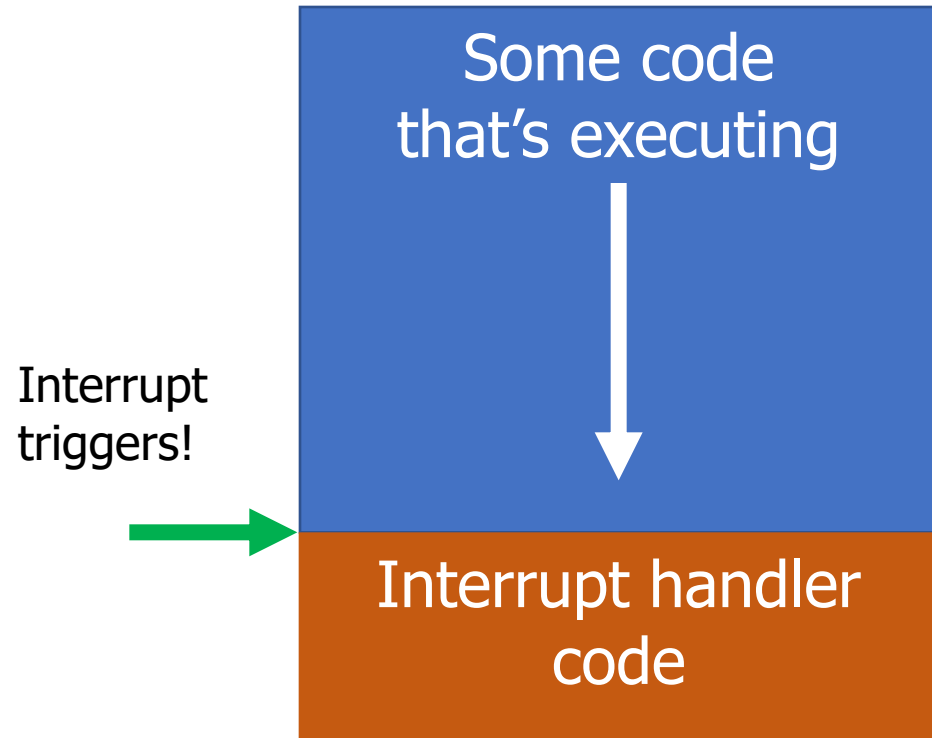
Interrupts

- What is an interrupt?
 - Some event which causes the processor to stop normal execution
 - The processor instead jumps to a software “handler” for that event
 - Then returns back to what it was doing afterwards
- What causes interrupts?
 - Hardware exceptions
 - Divide by zero, Undefined Instruction, Memory bus error
 - Software
 - Syscall, Software Interrupt (SWI)
 - External hardware
 - Input pin, Timer, various “Data Ready”

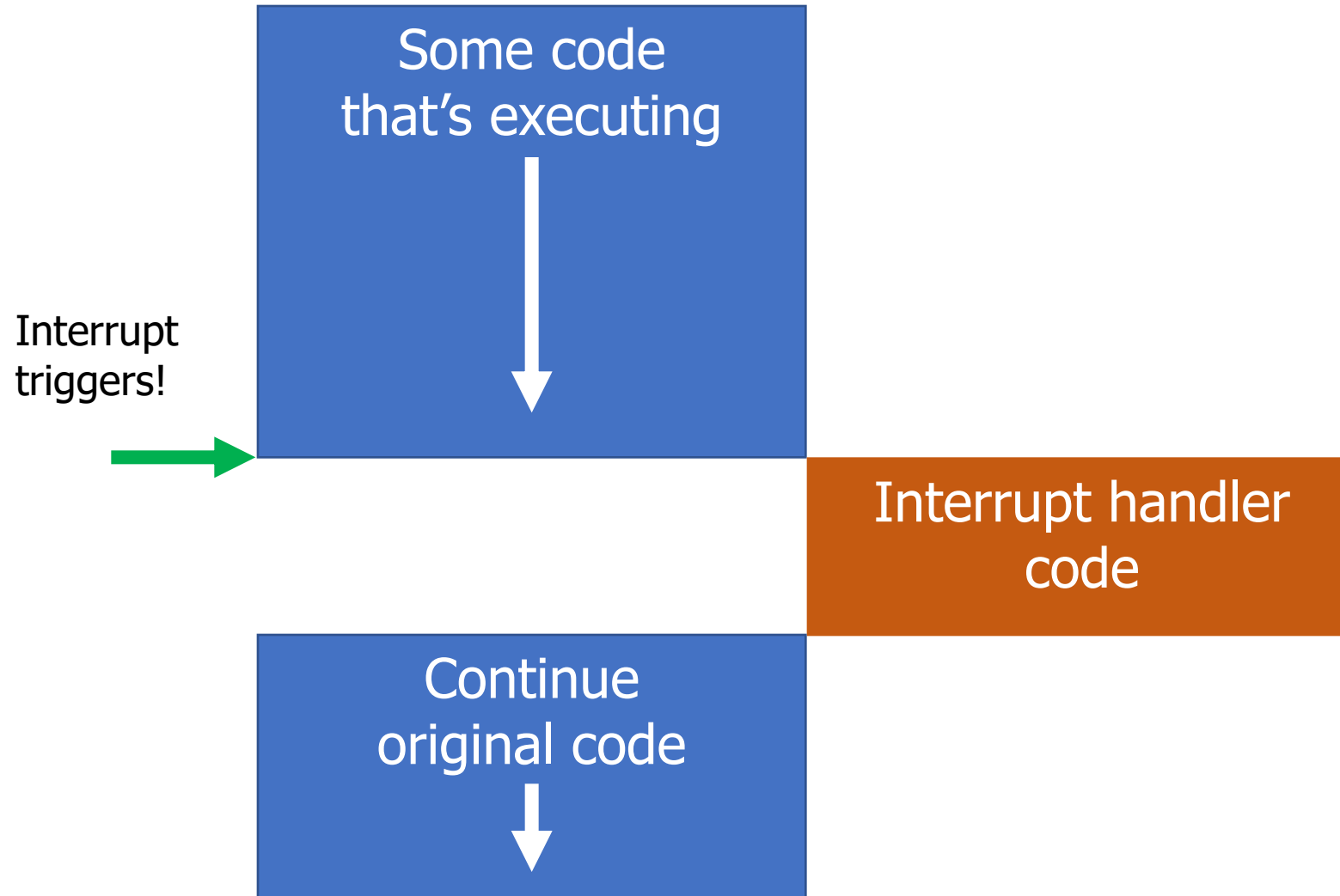
Interrupts, visually



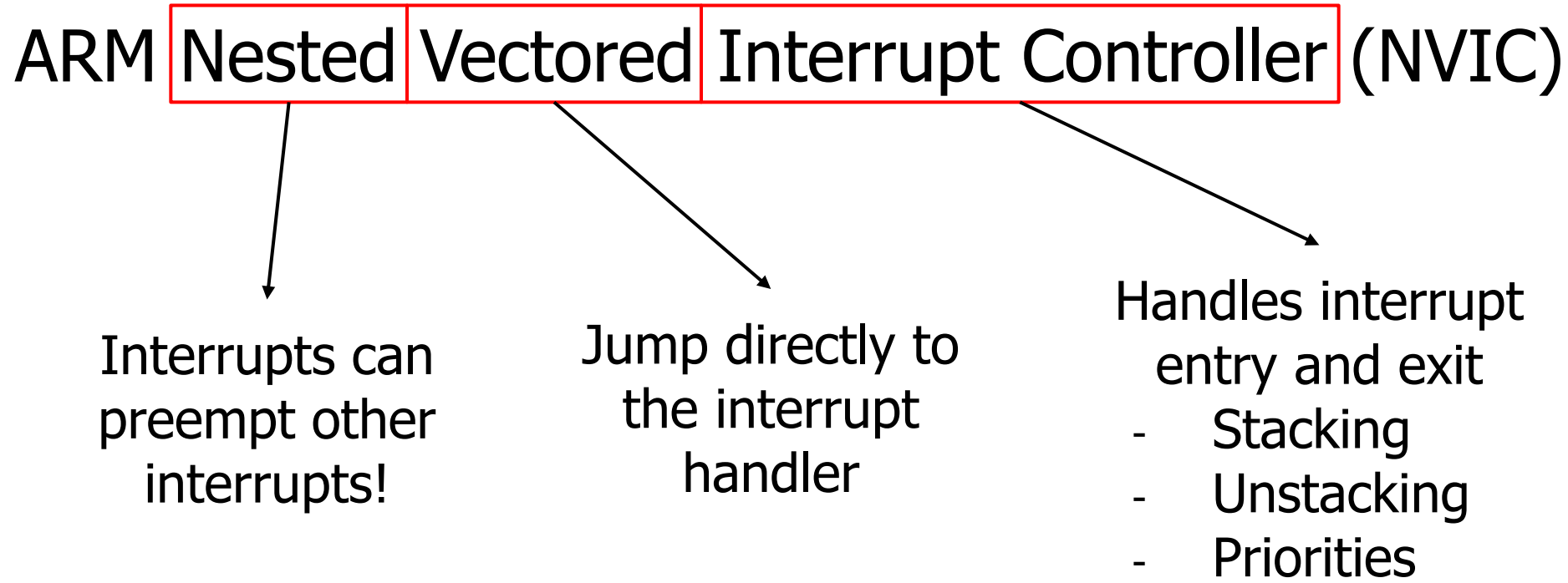
Interrupts, visually



Interrupts, visually



ARM Nested Vectored Interrupt Controller (NVIC)



Interrupts can preempt other interrupts!

Jump directly to the interrupt handler

Handles interrupt entry and exit

- Stacking
- Unstacking
- Priorities

- Manages interrupt requests (IRQ)
 - Stores all caller-saved registers on the stack
 - So the handler code doesn't overwrite them
 - Moves execution to proper handler, a.k.a. Interrupt Service Routine (ISR)
 - Restores registers after handler returns and moves execution back

ARM Vector table

- List of function pointers to handler for each interrupt/exception
- First 15 are architecture-specific exceptions
- After that are microcontroller interrupt signals

Table 7.1 List of System Exceptions

Exception Number	Exception Type	Priority	Description
1	Reset	−3 (Highest)	Reset
2	NMI	−2	Nonmaskable interrupt (external NMI input)
3	Hard fault	−1	All fault conditions if the corresponding fault handler is not enabled
4	MemManage fault	Programmable	Memory management fault; Memory Protection Unit (MPU) violation or access to illegal locations
5	Bus fault	Programmable	Bus error; occurs when Advanced High-Performance Bus (AHB) interface receives an error response from a bus slave (also called <i>prefetch abort</i> if it is an instruction fetch or <i>data abort</i> if it is a data access)
6	Usage fault	Programmable	Exceptions resulting from program error or trying to access coprocessor (the Cortex-M3 does not support a coprocessor)
7–10	Reserved	NA	—
11	SVC	Programmable	Supervisor Call
12	Debug monitor	Programmable	Debug monitor (breakpoints, watchpoints, or external debug requests)
13	Reserved	NA	—
14	PendSV	Programmable	Pendable Service Call
15	SYSTICK	Programmable	System Tick Timer

Table 7.2 List of External Interrupts

Exception Number	Exception Type	Priority
16	External Interrupt #0	Programmable
17	External Interrupt #1	Programmable
...	...	...
255	External Interrupt #239	Programmable

Vector table in software

- Placed in its own section
 - LD file puts it first in Flash
- Reset_Handler determines where software starts executing
- After that are all exception and interrupt handlers
 - All function pointers to some C code somewhere matched by function name

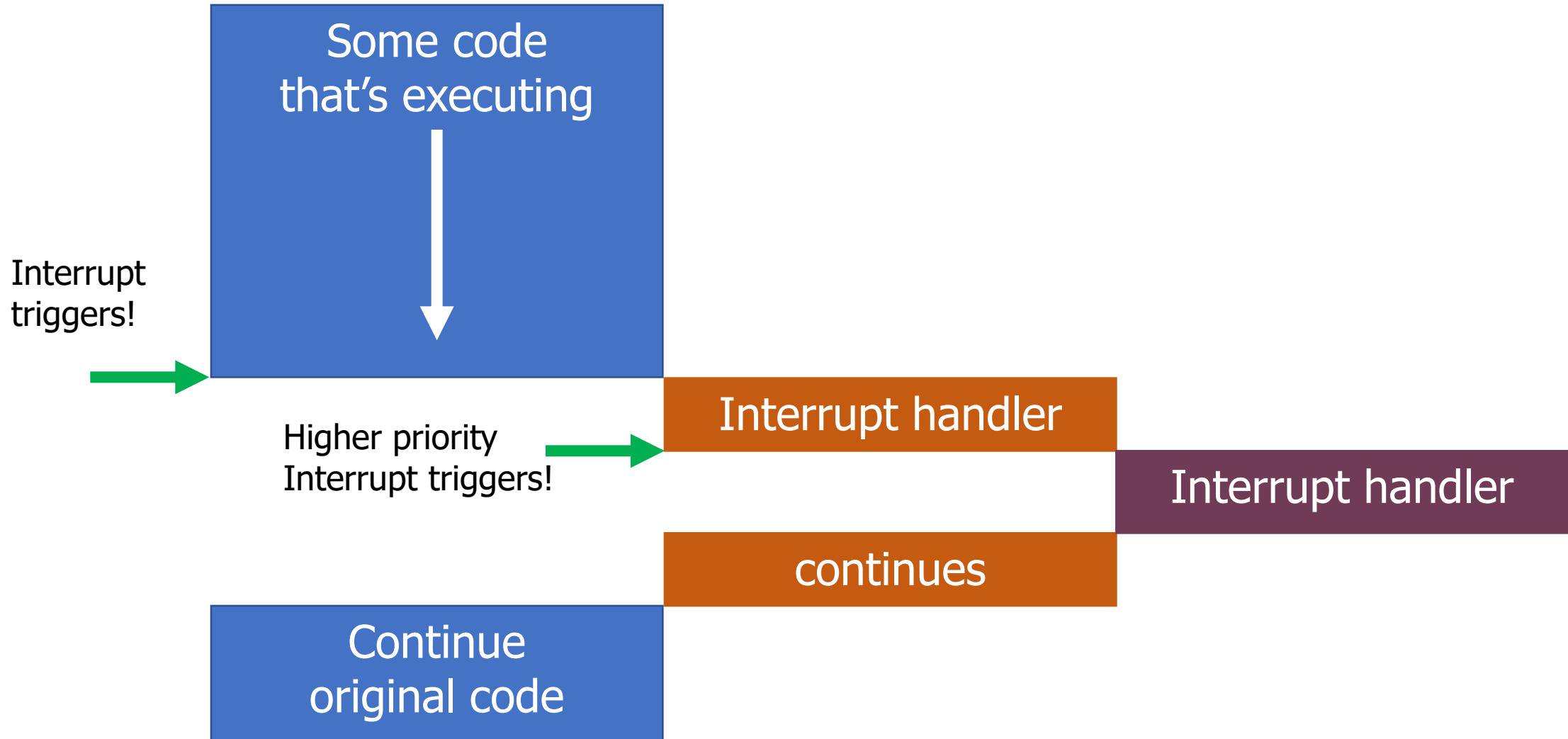
```
.section .isr_vector
.align 2
.globl __isr_vector
__isr_vector:
    .long    __StackTop           /* Top of Stack */
    .long    Reset_Handler
    .long    NMI_Handler
    .long    HardFault_Handler
    .long    MemoryManagement_Handler
    .long    BusFault_Handler
    .long    UsageFault_Handler
    .long    0                   /*Reserved */
    .long    0                   /*Reserved */
    .long    0                   /*Reserved */
    .long    0                   /*Reserved */
    .long    SVC_Handler
    .long    DebugMon_Handler
    .long    0                   /*Reserved */
    .long    PendSV_Handler
    .long    SysTick_Handler

    /* External Interrupts */
    .long    POWER_CLOCK_IRQHandler
    .long    RADIO_IRQHandler
    .long    UART0_UART1_IRQHandler
    .long    SPI0_SPIS0_TWIM0_TWI0_SPI0_TWI0_IRQHandler
    .long    SPI1_SPIS1_TWIM1_TWI1_SPI1_TWI1_IRQHandler
    .long    NCT_IRQHandler
    .long    GPIOTE_IRQHandler
    .long    SAADC_IRQHandler
```


ARM NVIC functionality

- NVIC functions
 - `NVIC_EnableIRQ(number)`
 - `NVIC_DisableIRQ(number)`
 - `NVIC_SetPriority(number, priority)`
 - Technically 256 priorities
 - Only 8 are implemented
- Must enable interrupts in two places!
 - Enabling event in the peripheral will generate the signal
 - Enabling interrupt in the NVIC will act on the signal, calling handler function
- Priority determines which interrupt goes first
 - And determines how interrupts are nested

Nested interrupts, visually



Generating interrupts on the nRF52

- Peripherals can generate “events”
 - 1-bit fields that get set when action occurs
 - There are Event registers that store the value
- Peripherals can enable interrupts
 - Which connects the Event to the NVIC
 - ALSO has to be enabled in the NVIC to actually get an Interrupt
- Advanced feature: Events can chain directly into Tasks
 - Tasks are 1-bit actions that a peripheral can take
 - Something occurring can automatically trigger something else to happen
 - PPI is the peripheral that makes these connections
 - (this is advanced stuff though, we'll rarely use it if ever)

Example “EVENT” register

EVENTS_OVRFLW

Address offset: 0x104

Event on COUNTER overflow

Bit number	31 30 29 28 27 26 25 24 23 22 21 20 19 18 17 16 15 14 13 12 11 10 9 8 7 6 5 4 3 2 1 0																														
ID	A																														
Reset 0x00000000	0 0																														
ID	R/W	Field	Value ID	Value	Description																										
A	RW	EVENTS_OVRFLW			Event on COUNTER overflow																										
			NotGenerated	0	Event not generated																										
			Generated	1	Event generated																										

- nRF-specific concept
 - Event registers record if some action has occurred
 - They are always 1-bit, with a 1 meaning “the action has occurred”
 - Up to the software to clear this register back to 0

Example “TASK” register

TASKS_START

Address offset: 0x000

Start RTC COUNTER

Bit number			31 30 29 28 27 26 25 24 23 22 21 20 19 18 17 16 15 14 13 12 11 10 9 8 7 6 5 4 3 2 1 0																															
ID			A																															
Reset 0x00000000			0 0																															
ID	R/W	Field	Value	ID	Value	Description																												
A	W	TASKS_START				Start RTC COUNTER																												
			Trigger	1		Trigger task																												

- nRF-specific concept
 - Task registers start some action
 - They are always 1-bit, with a 1 meaning “start the task”

Break + Open Question

- When should a system use polling versus interrupts?

Break + Open Question

- When should a system use polling versus interrupts?
- Polling
 - Great if the device is going to respond immediately (like 1 cycle)
 - Important if we need to respond very quick (less than a microsecond)
- Interrupts
 - Great if we'll need to wait a long time for status to change
 - Still responds pretty quickly, but not *immediately*
 - Needs to context switch from running code to interrupt handler

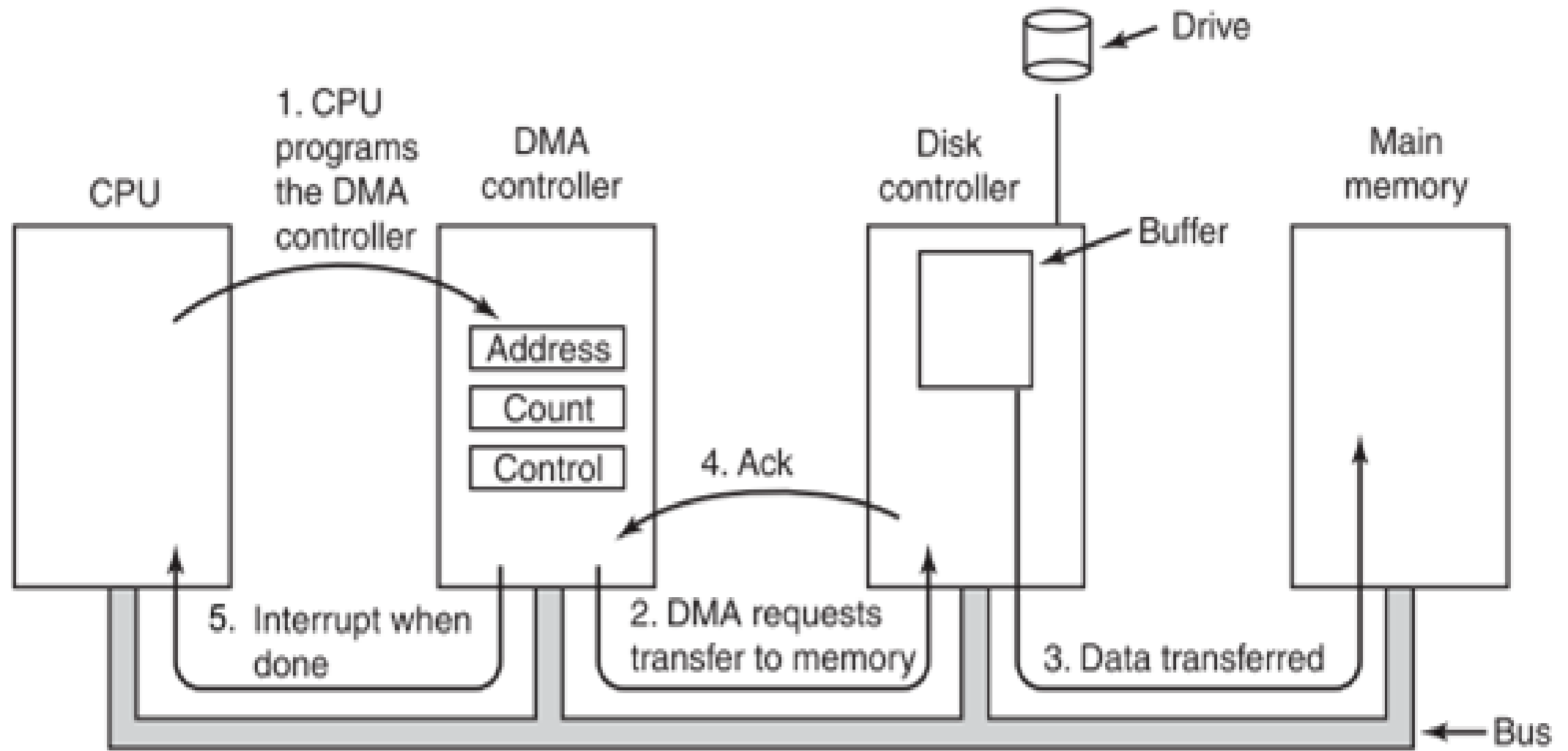
Outline

- I/O Motivation
- Interrupts
- **DMA (Direct Memory Access)**
- Controlling digital signals: GPO peripheral
- Digital input interrupts: GPIOTE peripheral

Direct Memory Access (DMA)

- Even with interrupts, providing data to the peripheral is time consuming for transferring lots of data
 - Need to be interrupted every byte, to copy the next byte over
- DMA is an alternative method that uses hardware to do the memory transfers for the processor
 - Software writes address of the data and the size to the peripheral
 - Peripheral reads data directly from memory
 - Processor can go do other things while read/write is occurring

General-purpose DMA



Full peripheral interaction pattern

1. Configure the peripheral
2. Enable peripheral interrupts
3. Set up peripheral DMA transfer
4. Start peripheral

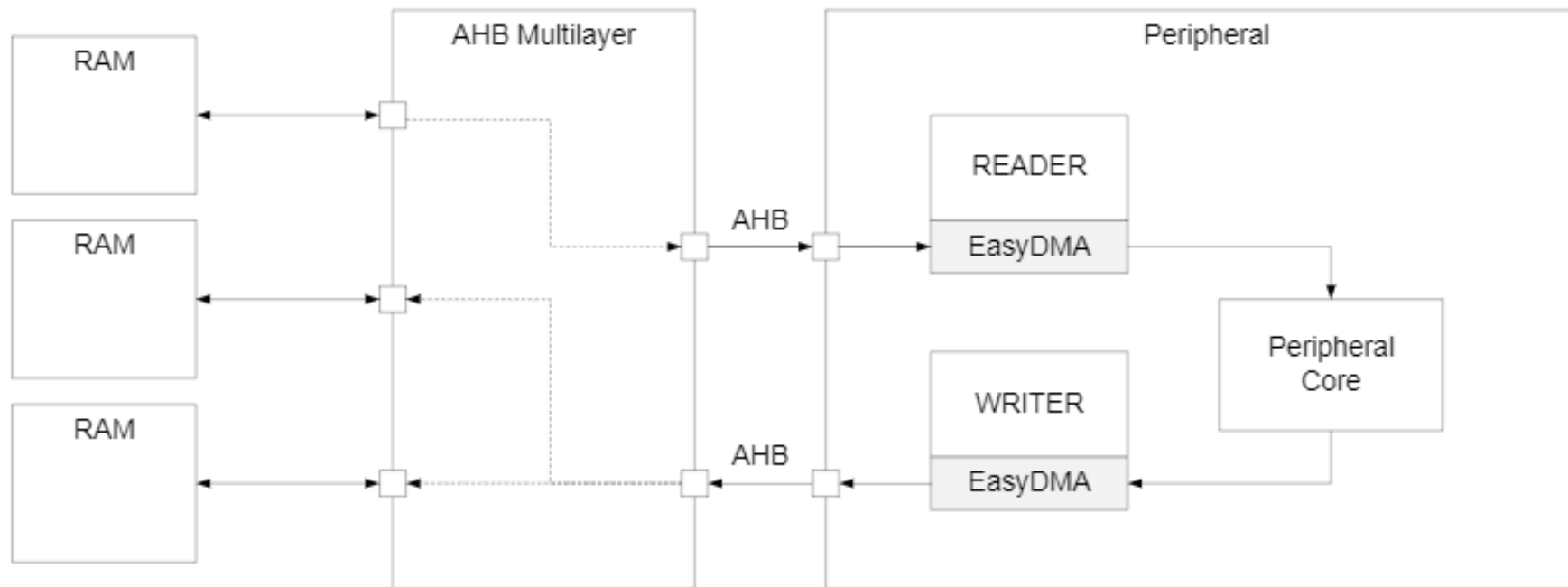
Continue on to other code

5. Interrupt occurs, signaling DMA transfer complete
6. Set up next DMA transfer

Continue on to other code, and repeat

Special-purpose DMA

- nRF52 uses “EasyDMA”, which is built into individual peripherals
 - Only capable of transferring data in/out of that peripheral
 - Easier to set up and use in practice
 - Only available on some peripherals though (no DMA for TEMP or GPIO)



Warning: addresses for DMA buffer MUST be in RAM!

Break + Question

- What kinds of peripherals/devices should you use the DMA for?

Break + Question

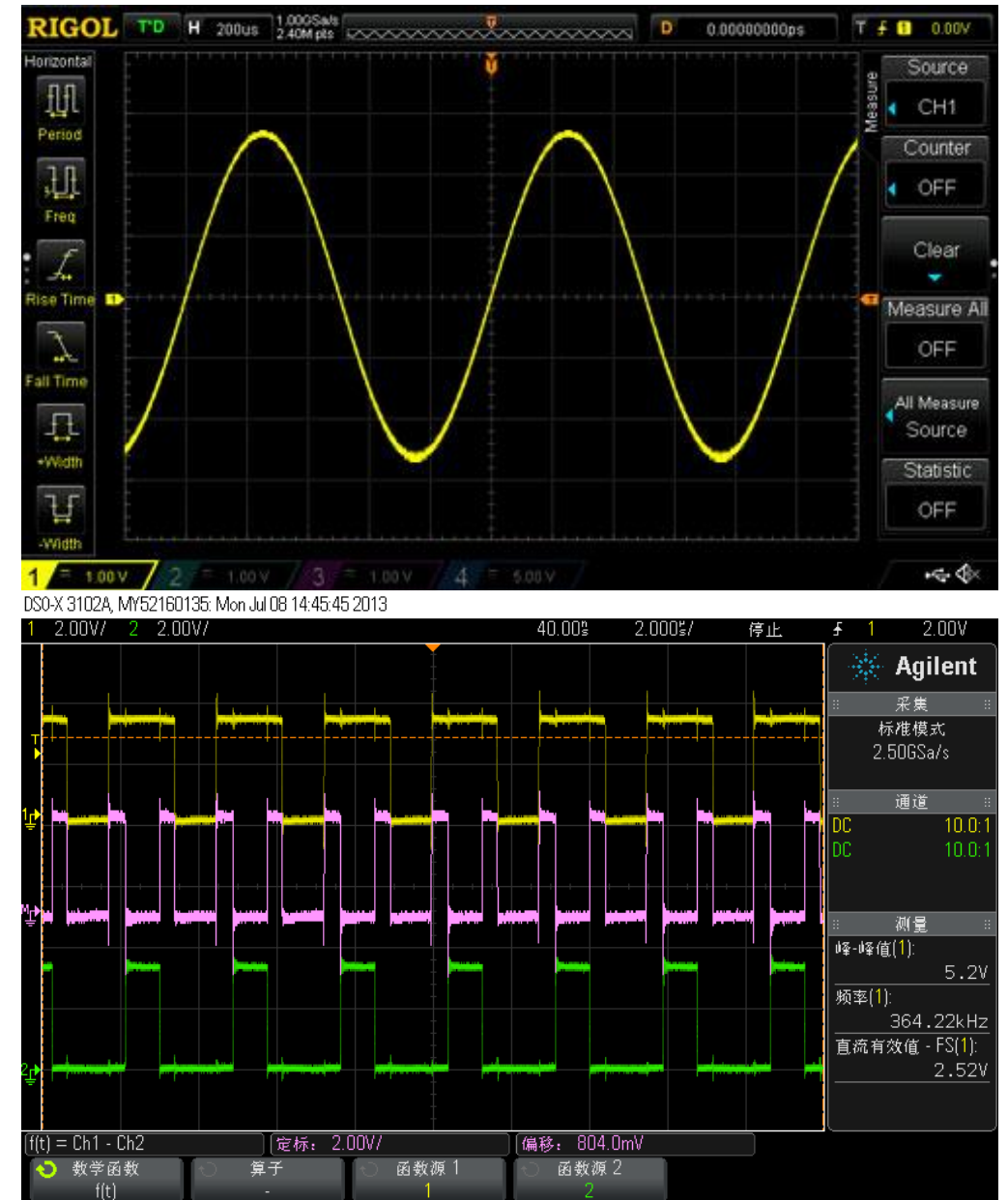
- What kinds of peripherals/devices should you use the DMA for?
 - Anything where there is a lot of data coming in over a period of time
 - Either a big buffer of lots of data, like a radio message
 - Or a bunch of individual samples, coming in quickly
 - Devices
 - Messages to/from other devices (radios, wired busses)
 - Sensor readings (if read quickly/continuously)
 - Canonical example from general computing: disks (HDD/SSD)

Outline

- I/O Motivation
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- DMA (Direct Memory Access)
- **Controlling digital signals: GPIO peripheral**
- Digital input interrupts: GPIOTE peripheral

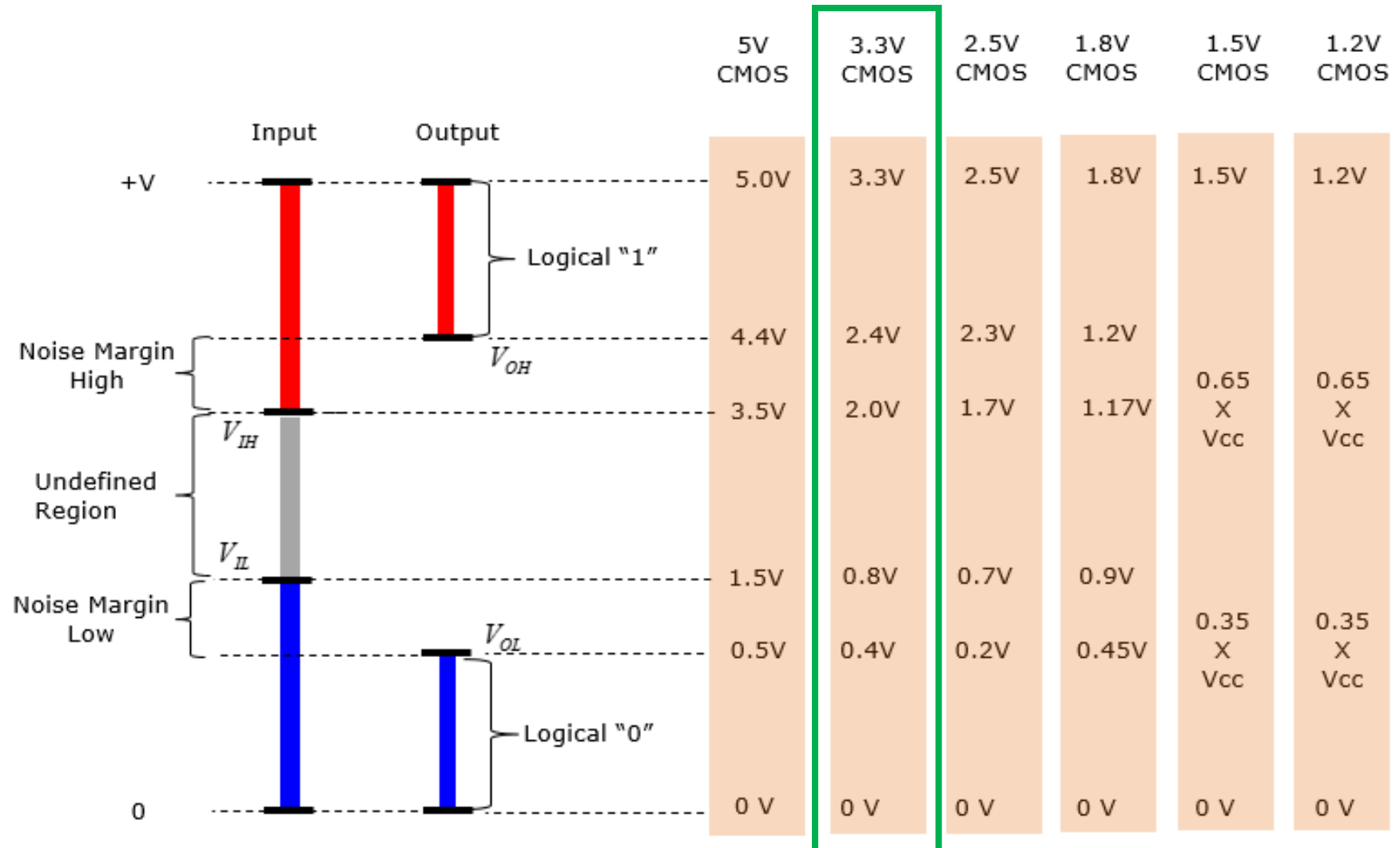
Digital signals

- Simplest form of I/O
- Exist in two states:
 - High (a.k.a. Set, a.k.a. 1)
 - Low (a.k.a. Clear, a.k.a. 0)
- Simpler to interact with
 - Constrained to two voltages
 - With quick transitions between the two
- No math for voltage level
 - Either high or low



Digital signals map to voltage ranges

- Upper range is high signal
 - $\sim 0.7 \cdot V_{DD}$
- Bottom range is low signal
 - $\sim 0.3 \cdot V_{DD}$
- Middle is undefined
 - Only exists during transitions



Digital Input/Output

- Read/write from/to external pins on the microcontroller
 - Two possible values: high (1) or low (0)
- Basic unit of operation for microcontrollers
 - Allows them to interact with buttons and LEDs
 - Many computer-to-computer wired protocols are digital
 - Every microcontroller has Digital I/O



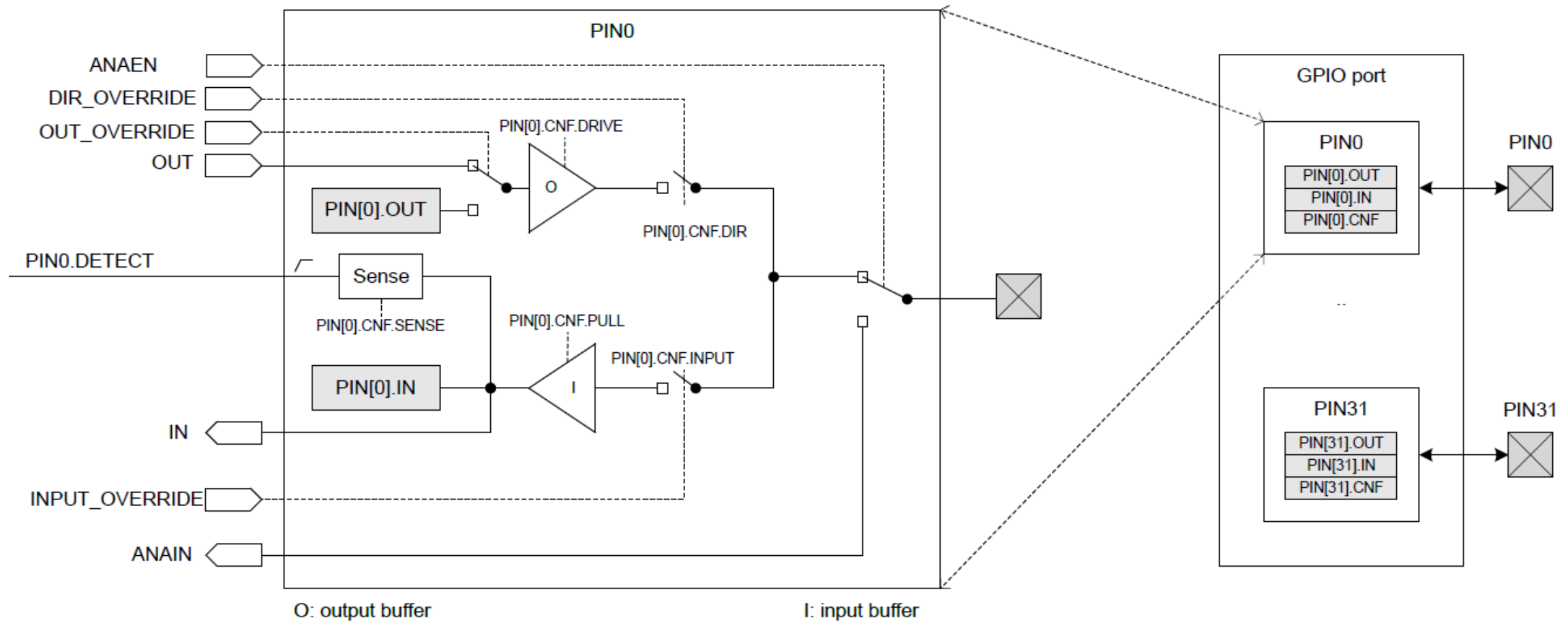
Some terminology

- Pins can be inputs or outputs
- Output pins can be:
 - High or Set or 1
 - Low or Cleared or 0
- Input pins can read an externally connected value
 - Which is translated into either High or Low
 - Middle remains undefined. It'll be High or Low though

Controlling Digital I/O

- Outputs
 - Configure pin as an output
 - Set or Clear it
- Inputs
 - Configure pin as an input
 - Read it
- That's about it. Digital I/O peripherals all look something like this
 - Every Digital I/O peripheral also has some "special features" of some kind or another, which vary with the Microcontroller

nRF52833 GPIO Peripheral



nRF52 GPIO Output

- Outputs a high or low signal
- Output configurations
 - High drive output (either for high, low, or both)
 - Sources or sinks additional current
 - For powering external devices
 - Normal drive: ~ 2 mA
 - High drive: ~ 10 mA
 - Disconnect (a.k.a. High Impedance or High-Z)
 - Wired-OR or Wired-AND scenarios (we'll talk about these later in class)

nRF52 GPIO Input

- Reads in a signal as either high or low
- Input Configurations
 - Input buffer connect/disconnect
 - Allows the pin to be completely disabled if not being read from
 - Pull
 - Disabled, Pulldown, Pullup (we'll discuss in a future lecture)
 - Connects an internal pull up/down resistor ($\sim 13 \text{ k}\Omega$)
 - Sets default value of input

Electrical specifications

- High voltage range: $0.7 \times VDD$ to VDD (~ 2.3 volts)
- Low voltage range: Ground to $0.3 \times VDD$ (~ 1 volt)
- GPIO are extremely fast
 - Transition time is < 25 ns
 - Connected directly to memory bus for faster interactions
- This allows complicated signal patterns to be replicated in software
 - If they aren't implemented as a hardware peripheral
 - Known as "bit-banging"

GPIO Instances

- The nRF52833 has two GPIO peripheral “instances”
 - Several peripherals have multiple instances. For example, multiple timers
 - Each instance functions independently
 - Each instance has its own copy of MMIO registers
- For the GPIO, each instance controls one Port
 - Port 0 with 32 pins
 - Port 1 with 10 pins

Instance	Base address	Description
GPIO	0x50000000	General purpose input and output This instance is deprecated.
P0	0x50000000	General purpose input and output, port 0
P1	0x50000300	General purpose input and output, port 1

Accessing nRF52833 pins in software

- Pins are collected into “Ports”
 - Each Port has 32 pins
- 42 total GPIO pins
 - Port 0 – pins 0-31
 - Port 1 – pins 0-9
- Referred to as `P[port].[pin]`
 - For example: P0.20, P1.08, P0.00

Pin configuration

6.8.2.5 DIR

Address offset: 0x514

Direction of GPIO pins

Bit number			31 30 29 28 27 26 25 24 23 22 21 20 19 18 17 16 15 14 13 12 11 10 9 8 7 6 5 4 3 2 1 0																															
ID			f e d c b a Z Y X W V U T S R Q P O N M L K J I H G F E D C B A																															
Reset 0x00000000			0 0																															
ID	Acce Field	Value ID	Value	Description																														
A-f	RW	PIN[i] (i=0..31)		Pin i																														
		Input	0	Pin set as input																														
		Output	1	Pin set as output																														

- DIR register controls direction (input or output) for each pin
 - Each bit 0-31 corresponds to pin 0-31
 - Reset value: 0x00000000 -> all pins are inputs by default

Controlling output level

6.8.2.1 OUT

Address offset: 0x504

Write GPIO port

Bit number			31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16	15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
ID			f	e	d	c	b	a	Z	Y	X	W	V	U	T	S	R	Q	P	O	N	M	L	K	J	I	H	G	F	E	D	C	B	A
Reset 0x00000000			0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
ID	Acce Field	Value ID	Value		Description																													

A-f RW PIN[i] (i=0..31)

Pin i

Low

0

Pin driver is low

High

1

Pin driver is high

- OUT register controls whether each pin is high or low
 - Only meaningful if the pin is configured as an Output
 - Again, each bit is a single pin and reset is 0x00000000 (all pins low)

*Set/*Clear registers

Register	Offset	Description
OUT	0x504	Write GPIO port
OUTSET	0x508	Set individual bits in GPIO port
OUTCLR	0x50C	Clear individual bits in GPIO port
IN	0x510	Read GPIO port
DIR	0x514	Direction of GPIO pins
DIRSET	0x518	DIR set register
DIRCLR	0x51C	DIR clear register

- OUT works traditionally: write a 1 for high, 0 for low
- OUTSET write a 1 to set that pin (high) zero has no effect
- OUTCLR write a 1 to clear that pin (low) zero has no effect
 - Lets you modify a pin without modifying the others (or reading first)

Reading input levels

6.8.2.4 IN

Address offset: 0x510

Read GPIO port

Bit number				31 30 29 28 27 26 25 24 23 22 21 20 19 18 17 16 15 14 13 12 11 10 9 8 7 6 5 4 3 2 1 0																															
ID				f e d c b a Z Y X W V U T S R Q P O N M L K J I H G F E D C B A																															
Reset 0x00000000				0 0																															
ID	Acce Field		Value ID	Value				Description																											
A-f	R	PIN[i] (i=0..31)						Pin i																											
			Low	0				Pin input is low																											
			High	1				Pin input is high																											

- IN register allows you to read the value for an input pin
 - Each bit 0-31 corresponds to pin 0-31
 - Read-only register. Writing has no effect
 - For Port1, pins ≥ 10 are *undefined* (data sheet doesn't mention it)

Complex configuration

- If you want to change other pin configurations, you do so per pin with the `PIN_CNF[n]` registers
 - There are 32 of them, one per pin
- Various fields correspond to different groups of bits
 - Direction, Input buffer, Pullup/down, Drive strength, Sensing mechanism
- Bits not part of a field should be ignored
 - Do not modify them

Bit number			31 30 29 28 27 26 25 24 23 22 21 20 19 18 17 16 15 14 13 12 11 10 9 8 7 6 5 4 3 2 1 0																															
ID			E E																D D D								C C B A							
Reset 0x00000002			0 1 0																															
ID	Acce Field	Value ID	Value	Description																														
A	RW DIR			Pin direction. Same physical register as DIR register																														
		Input	0	Configure pin as an input pin																														
		Output	1	Configure pin as an output pin																														
B	RW INPUT			Connect or disconnect input buffer																														
		Connect	0	Connect input buffer																														
		Disconnect	1	Disconnect input buffer																														
C	RW PULL			Pull configuration																														
		Disabled	0	No pull																														
		Pulldown	1	Pull down on pin																														
		Pullup	3	Pull up on pin																														
D	RW DRIVE			Drive configuration																														
		S0S1	0	Standard '0', standard '1'																														
		H0S1	1	High drive '0', standard '1'																														
		S0H1	2	Standard '0', high drive '1'																														
		H0H1	3	High drive '0', high 'drive '1"																														
		D0S1	4	Disconnect '0' standard '1' (normally used for wired-or connections)																														
		D0H1	5	Disconnect '0', high drive '1' (normally used for wired-or connections)																														
		S0D1	6	Standard '0'. disconnect '1' (normally used for wired-and connections)																														
		H0D1	7	High drive '0', disconnect '1' (normally used for wired-and connections)																														
E	RW SENSE			Pin sensing mechanism																														
		Disabled	0	Disabled																														
		High	2	Sense for high level																														
		Low	3	Sense for low level																														

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Break + Question

- Reset value is 0x2
- **What are the default configurations here?**

Bit number			31 30 29 28 27 26 25 24 23 22 21 20 19 18 17 16 15 14 13 12 11 10 9 8 7 6 5 4 3 2 1 0																															
ID			E E																D D D								C C B A							
Reset 0x00000002			0 1 0																															
ID	Acce Field	Value ID	Value	Description																														
A	RW DIR			Pin direction. Same physical register as DIR register																														
		Input	0	Configure pin as an input pin																														
		Output	1	Configure pin as an output pin																														
B	RW INPUT			Connect or disconnect input buffer																														
		Connect	0	Connect input buffer																														
		Disconnect	1	Disconnect input buffer																														
C	RW PULL			Pull configuration																														
		Disabled	0	No pull																														
		Pulldown	1	Pull down on pin																														
		Pullup	3	Pull up on pin																														
D	RW DRIVE			Drive configuration																														
		S0S1	0	Standard '0', standard '1'																														
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		H0D1	7	High drive '0', disconnect '1' (normally used for wired-and connections)																														
E	RW SENSE			Pin sensing mechanism																														
		Disabled	0	Disabled																														
		High	2	Sense for high level																														
		Low	3	Sense for low level																														

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Break + Question

- Reset value is 0x2
- **What are the default configurations here?**
 - DIR: Input
 - INPUT: Disconnected
 - PULL: Disabled
 - DRIVE: Standard 0/1
 - SENSE: Disabled

Bit number			31 30 29 28 27 26 25 24 23 22 21 20 19 18 17 16 15 14 13 12 11 10 9 8 7 6 5 4 3 2 1 0																															
ID			E E																D D D			C C B A												
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		H0D1	7	High drive '0', disconnect '1' (normally used for wired-and connections)																														
E	RW SENSE			Pin sensing mechanism																														
		Disabled	0	Disabled																														
		High	2	Sense for high level																														
		Low	3	Sense for low level																														

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Outline

- I/O Motivation
- Interrupts
- DMA (Direct Memory Access)
- Controlling digital signals: GPO peripheral
- **Digital input interrupts: GPIOTE peripheral**

Handling interrupts from GPIO

- Separate peripheral, GPIOTE (GPIO Task/Event)
 - Manages up to 8 individual pins (8 “channels”)
 - Can read input pins and trigger Events
 - Also has Tasks for setting/clearing outputs pins
- Unclear to me why this is a separate peripheral
 - Presumably too complicated/expensive to have 42 of them
 - Newest nRF54 series still does the same thing

Configuring individual input interrupts

- Pick an available GPIOTE channel (0-7)
- Configure it
 - Port and Pin number
 - Task (output), Event (input), or Disabled
 - Polarity for input events
 - Low-to-high
 - High-to-low
 - Toggle (both directions)
- Enable interrupts for channel in GPIOTE (and in NVIC!)
- Clear event in interrupt handler
 - Doesn't happen automatically!

What if you need more than 8 interrupt sources?

- Can trigger interrupts for a “Port event” as well
 - Any pin in the Port can trigger the interrupt
 - Software checks which pin(s) caused the event to occur
- Very low power operation (works with system clocks off)
 - Whereas normal GPIOTE operations are not low power

GPIO vs GPIOTE

- GPIO peripheral is used to
 - Configure, set/clear, and read pins normally from software
- GPIOTE peripheral is used to
 - Get an interrupt when an input pin changes
 - Advanced feature: also able modify output pins based on some event occurring
 - Hardware event triggers hardware task (again, rarely used)

Outline

- I/O Motivation
- Interrupts
- DMA (Direct Memory Access)
- Controlling digital signals: GPIO peripheral
- Digital input interrupts: GPIOTE peripheral