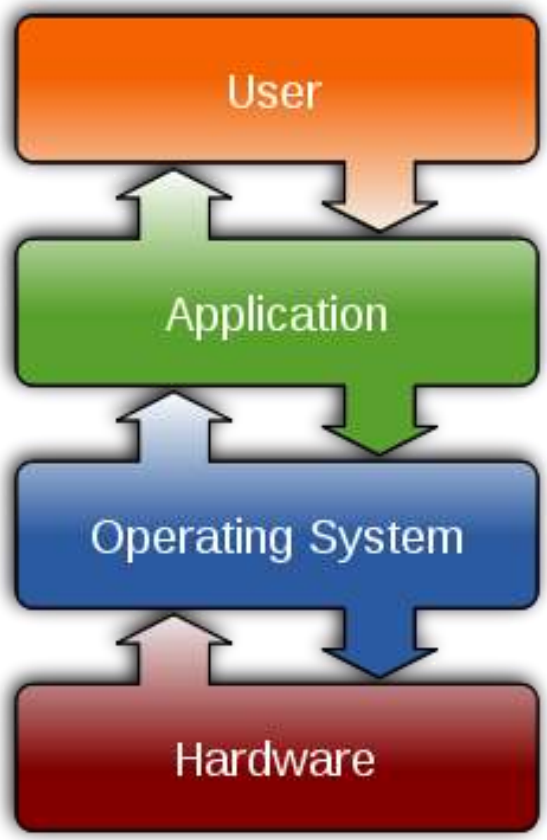
Introduction to SYS/BIOS

Outline

- **Intro to SYS/BIOS**
  - Overview
  - Threads and Scheduling
  - Creating a BIOS Thread
  - System Timeline
  - Real-Time Analysis Tools
  - Create A New Project
  - BIOS Configuration (.CFG)
  - Platforms
  - For More Info…..
- BIOS Threads



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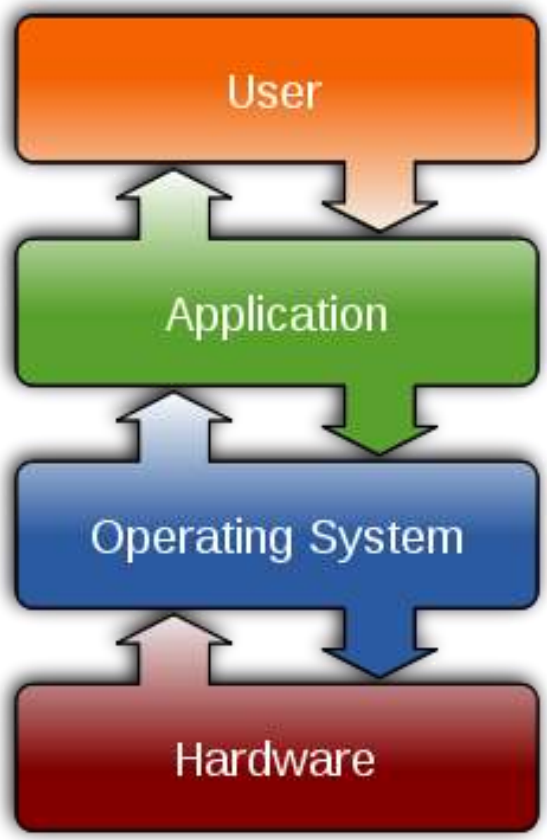
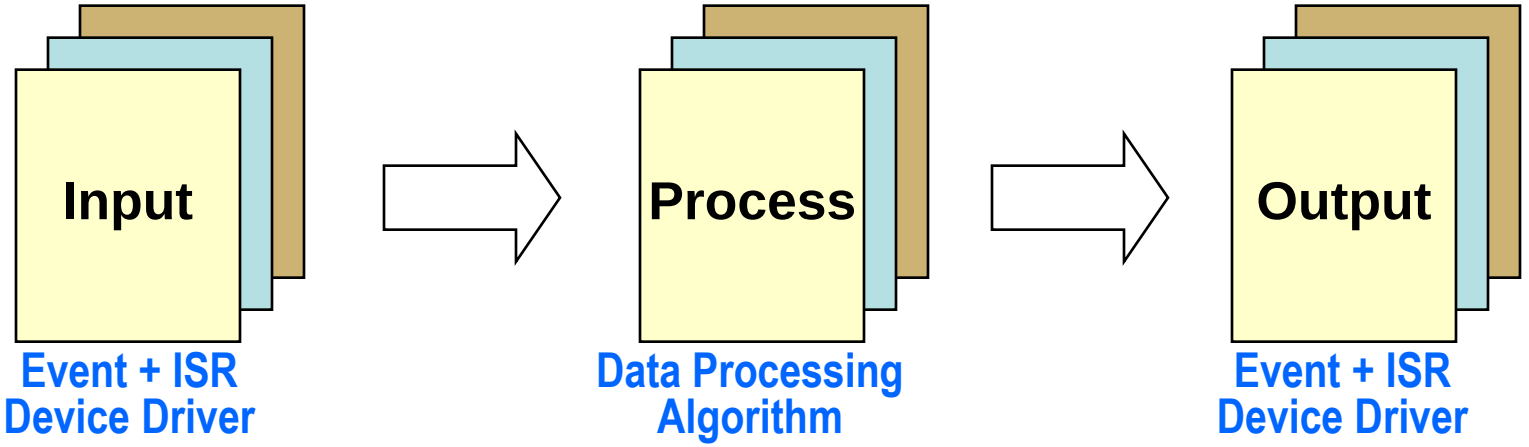
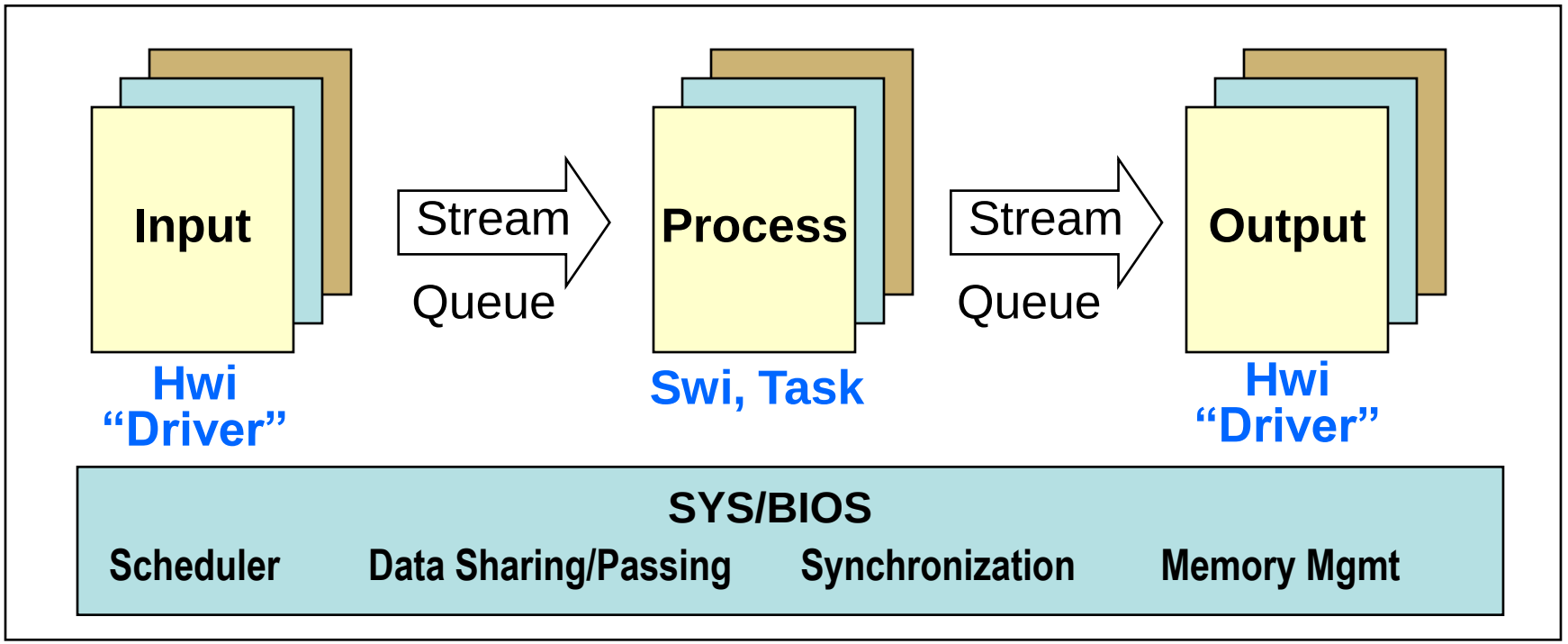


Need for an Operating System



- Simple system: single I-P-O is easy to manage
- As system complexity increases (multiple threads):
  - Can they all meet real time ?
  - Priorities of threads/algos ?
  - Synchronization of events?
  - Data sharing/passing ?
- 2 options: "home-grown" or use existing (SYS/BIOS)
  (either option requires overhead)
- If you choose an existing O/S, what should you consider ?
  - Is it modular ?
  - Is it easy to use ?
  - How much does it cost ?
  - Is it reliable?
  - Data sharing/passing ?
  - What code overhead exists?

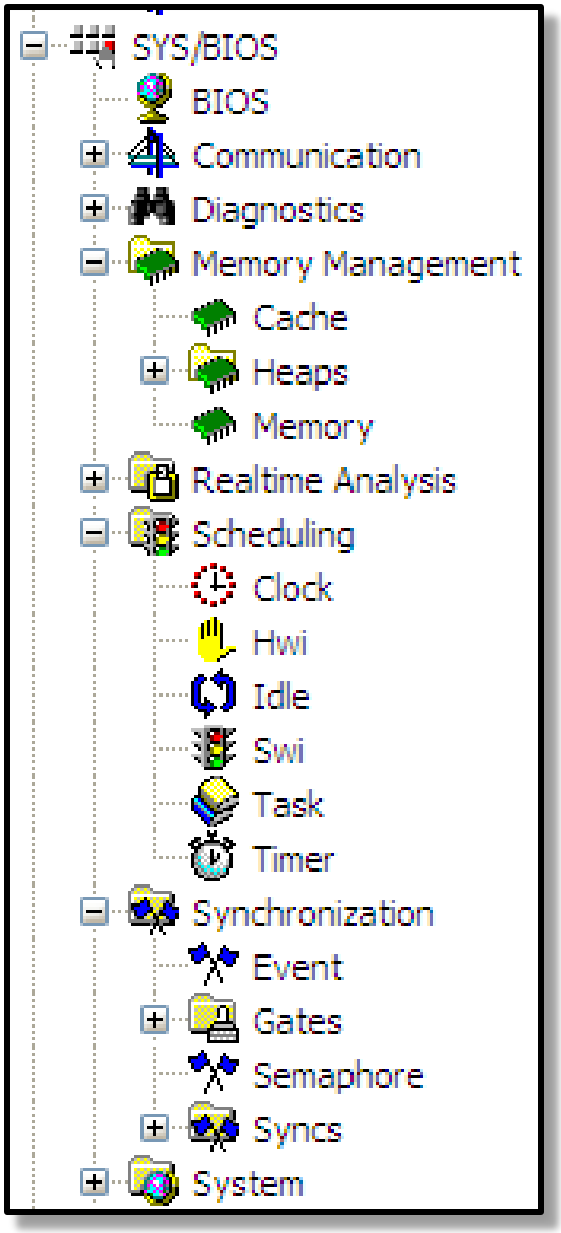
SYS/BIOS Overview



SYS/BIOS is a scalable, real-time kernel used in 1000s of systems today:

- Pre-emptive Scheduler to design system to meet real-time (including sync/priorities)
- Modular – pre-defined interface for inter-thread communications
- Reliable – 1000s of applications have used it for more than 10 years
- Footprint – deterministic, small code size, can choose which modules you desire
- Cost – free of charge

SYS/BIOS Modules & Services

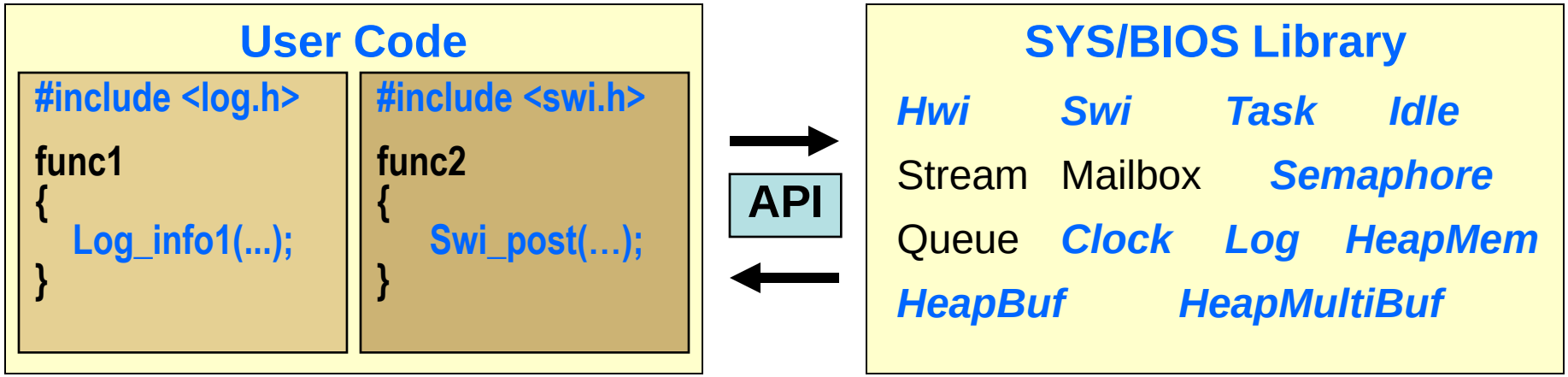


BIOS Configuration

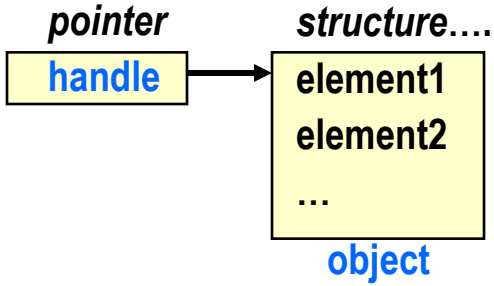
- **Memory Mgmt**
  - Cache & Heaps
- **Realtime Analysis**
  - Logs, Loads, Execution Graph
- **Scheduling**
  - All thread types
- **Synchronization**
  - Semaphores, Events, Gates

How do you interact with the SYS/BIOS services?

SYS/BIOS Environment



- SYS/BIOS is a library that contains modules with a particular interface and data structures
- Application Program Interfaces (API) define the interactions (methods) with a module and data structures (objects)
- Objects - are structures that define the state of a component
  - Pointers to objects are called handles
  - Object based programming offers:
    - *Better encapsulation and abstraction*
    - *Multiple instance ability*



Definitions / Vocabulary

- In this workshop, we'll be using these terms often:

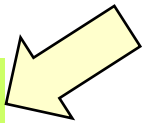
Real-time System

- *Where processing must keep up with the rate of I/O*

Function

- *Sequence of program instructions that produce a given result*

Thread



- *Function that executes within a specific context (regs, stack, PRIORITY)*

API

- *Application Programming Interface – "methods" for interacting with library routines and data objects*

RTOS vs GP/OS

	GP/OS (e.g. Linux)	RTOS (e.g. SYS/BIOS)
Scope	General	Specific
Size	Large: 5M-50M	Small: 5K-50K
Event response	1ms to .1ms	100 – 10 ns
File management	FAT, etc	FatFS
Dynamic Memory	Yes	Yes
Threads	Processes, pThreads, Ints	Hwi, Swi, Task, Idle
Scheduler	Time Slicing	Preemption
Host Processor	ARM, x86, Power PC	ARM, MSP430, M3, C28x, DSP

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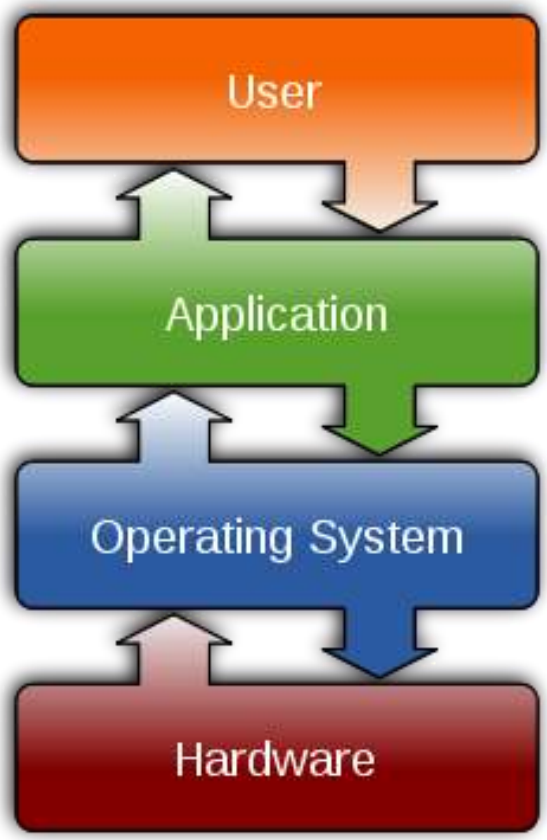


SYS/BIOS Thread Types

Hwi
Hardware Interrupts

- Implements 'urgent' part of real-time event
- Hardware interrupt triggers ISRs to run
- Priorities set by hardware

Swi
Software Interrupts

- Performs HWI '*follow-up*' activity
- '*posted*' by software
- Periodic (Clock) functions are prioritized as SWIs
- Up to 32 priority levels (16 on C28x)

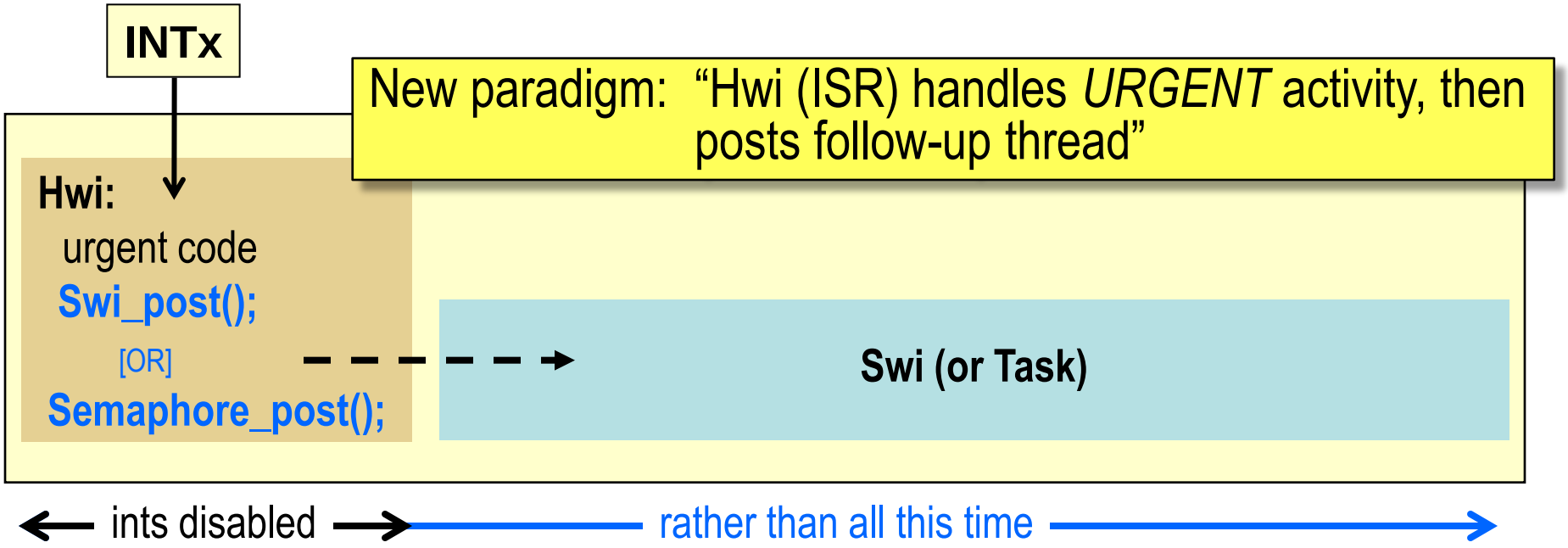
Task
Tasks

- Runs programs concurrently under separate contexts
- Usually enabled to run by posting a '*semaphore*' (a task signaling mechanism)
- Up to 32 priority levels (16 on C28x)

Idle
Background

- Multiple Idle functions
- Runs as an infinite loop (like traditional *while(1)* loop)
- Single priority level

Hwi's Signaling Swi/Task



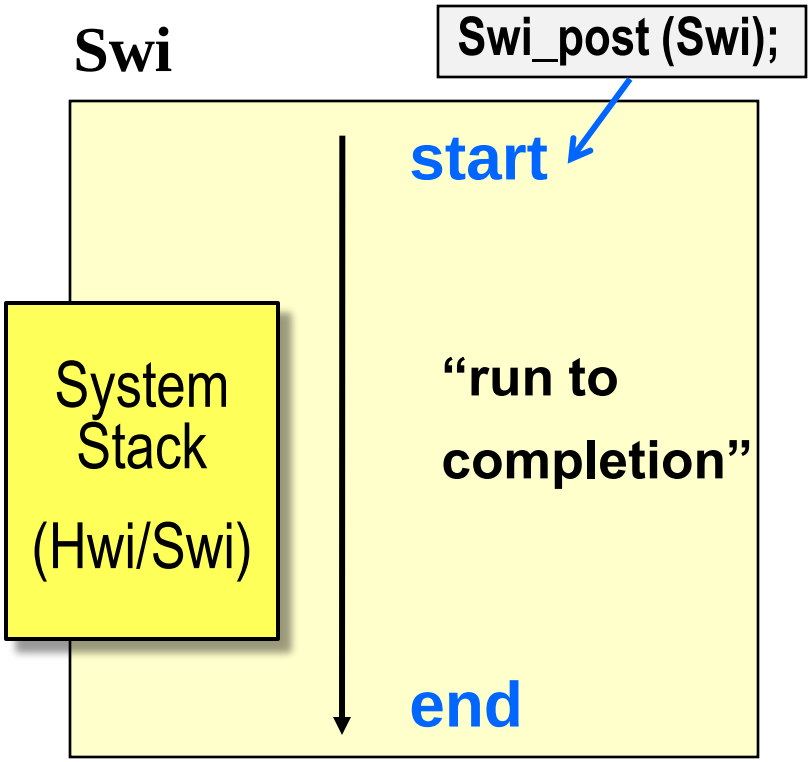
Hwi

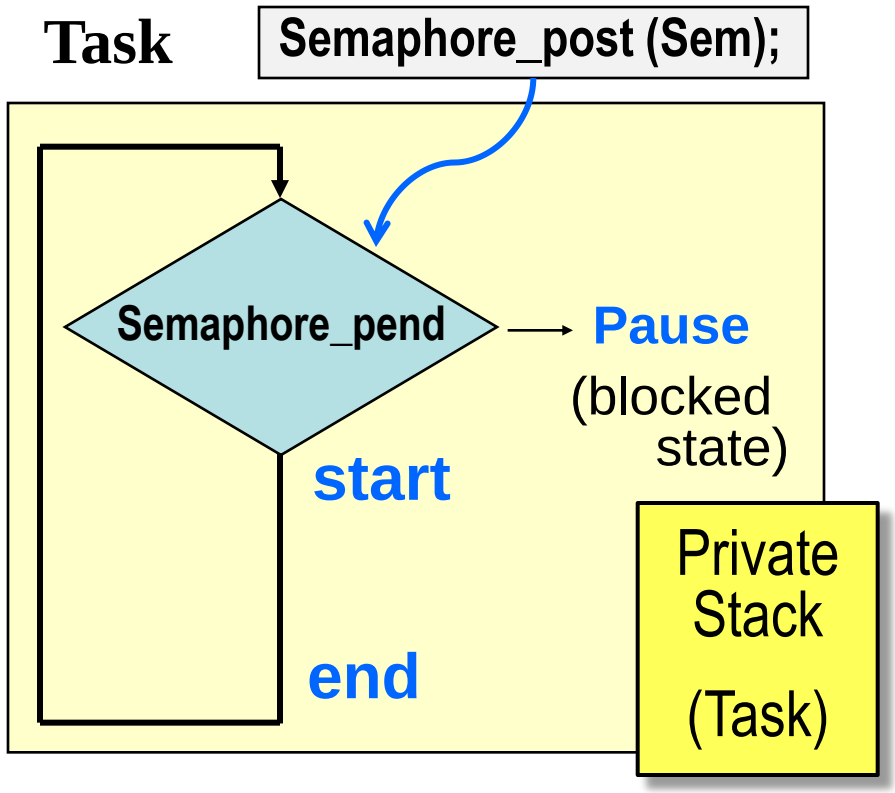
- Fast response to interrupts
- Minimal context switching
- High priority only
- Can post Swi
- Use for urgent code only – then post follow up activity

Swi

- Latency in response time
- Context switch performed
- Selectable priority levels
- Can post another Swi
- Execution managed by scheduler

Swi's and Tasks





- Similar to hardware interrupt, but triggered when posted
- All Swi's share system software stack with Hwi's

- Unblocking triggers execution (also could be mailbox, events, etc.)
- Each Task has its own stack, which allows them to pause (i.e. block)
- Topology: prologue, loop, epilogue…

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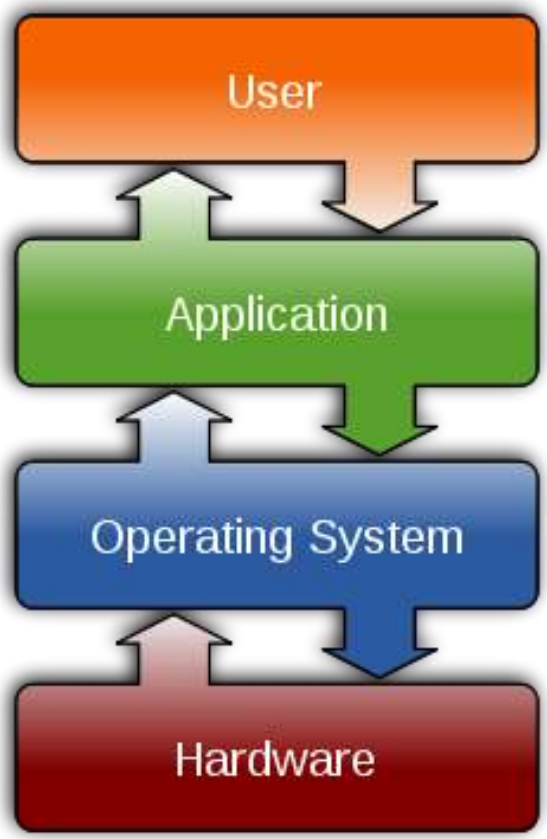


Thread (Object) Creation in BIOS

Users can create threads (BIOS resources or "objects"):

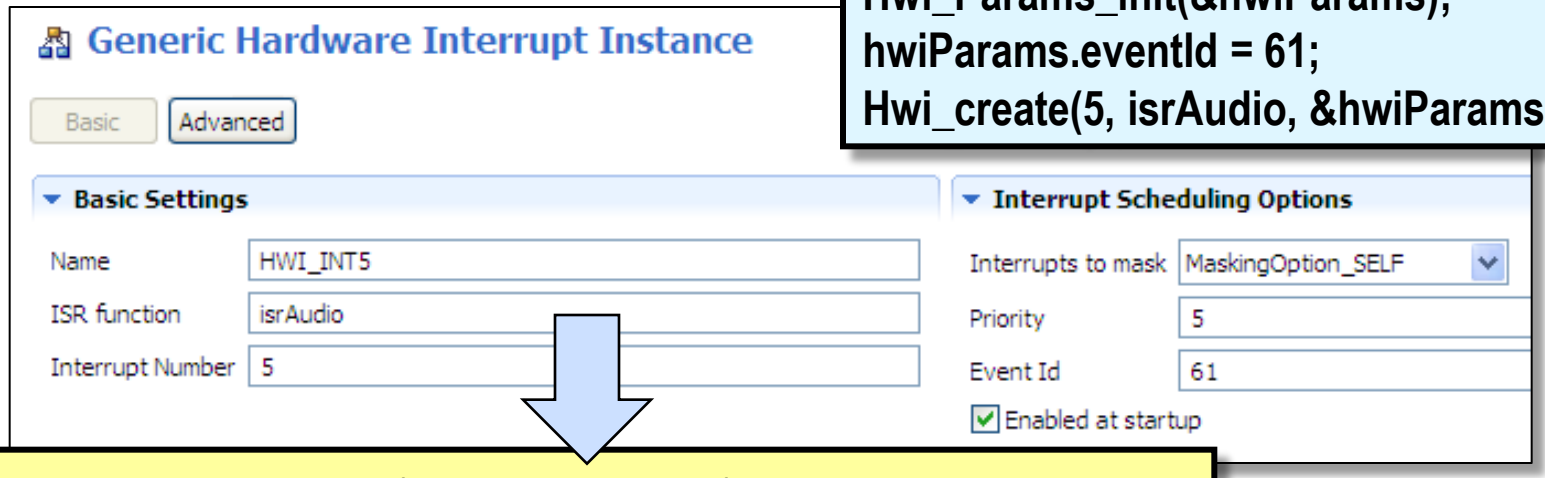
- Statically (via the GUI or .cfg script)
- Dynamically (via C code) – *more details in the "dynamic" chapter*
- BIOS doesn't care – but you might…

Dynamic (C Code)

```
#include <ti/sysbios/hal/Hwi.h>
Hwi_Params hwiParams;
Hwi_Params_init(&hwiParams);
hwiParams.eventId = 61;
Hwi_create(5, isrAudio, &hwiParams, NULL);
```

app.c

Static (GUI or Script)




```
var Hwi = xdc.useModule('ti.sysbios.hal.Hwi');
var hwiParams = new Hwi.Params();
hwiParams.eventId = 61;
Hwi.create(5, "&isrAudio", hwiParams);
```

app.cfg

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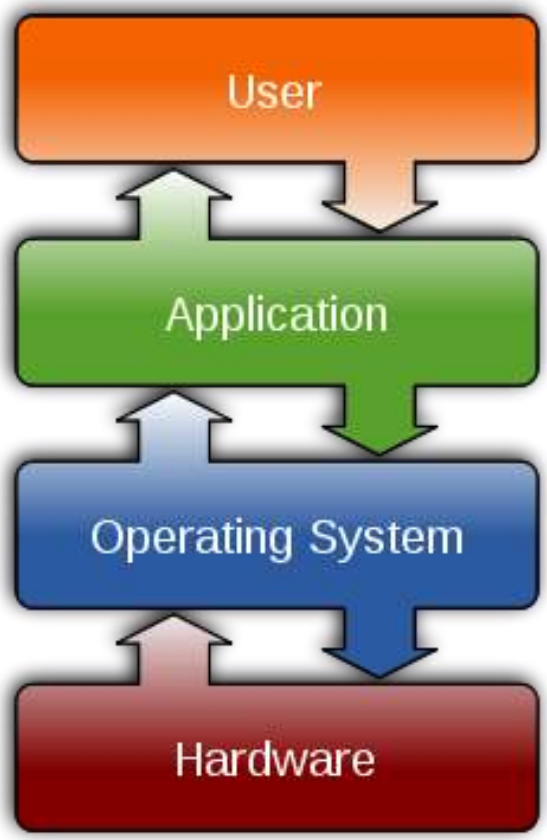
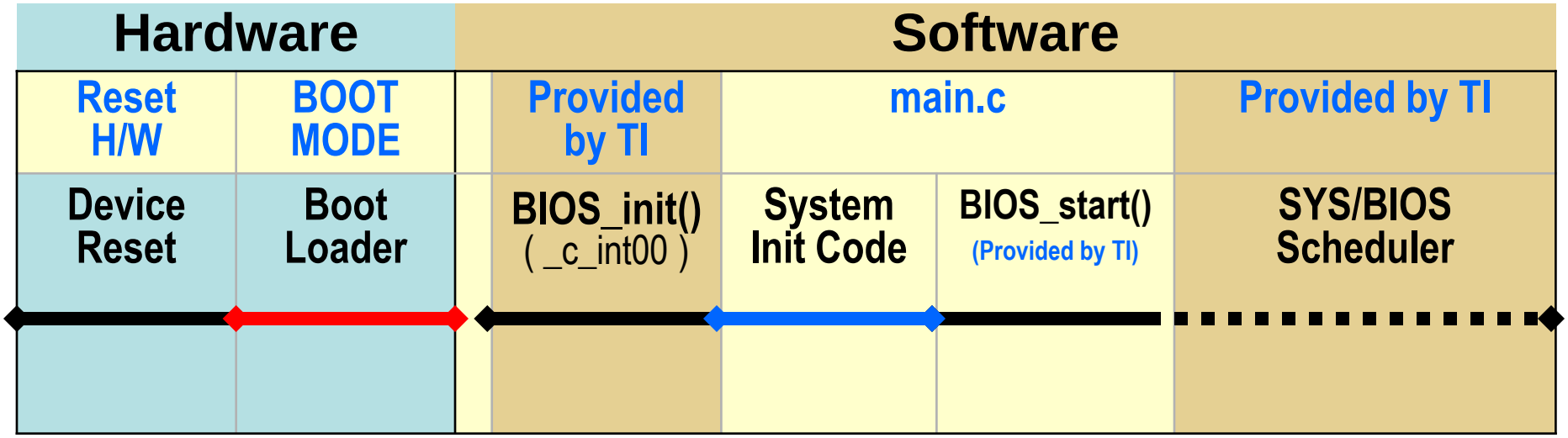


System Timeline



- **RESET – Device is reset, then jumps to bootloader or code entry point (`c_int00`)**
- **BOOT MODE – runs bootloader (if applicable)**
- **`BIOS_init()` – configs static BIOS objects, jumps to c_int00 to init Stack Pointer (SP), globals/statics, then calls `main()`**
- **`main()`**
  - **User initialization**
  - **Must execute `BIOS_start()` to enable BIOS Scheduler & INTs**

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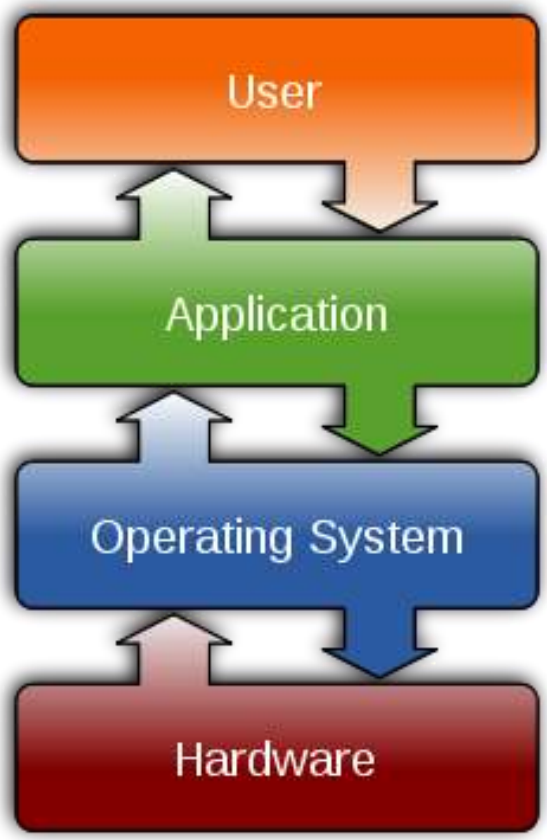
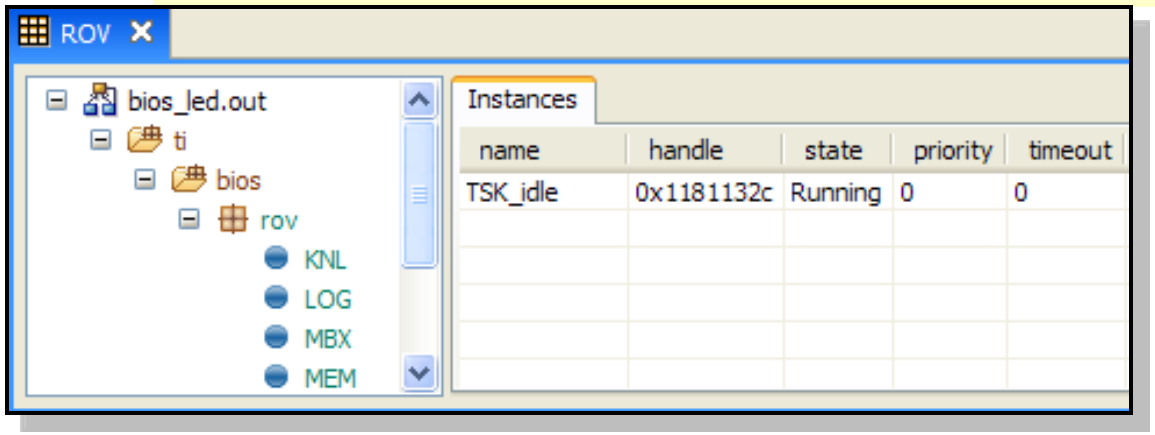


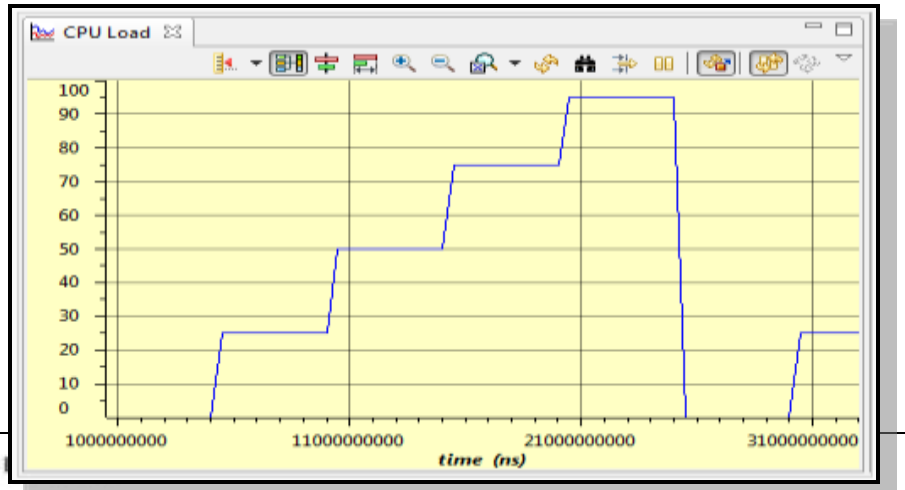
Built-in Real-Time Analysis Tools

- Gather data on target (30-40 CPU cycles)
- Format data on host (1000s of host PC cycles)
- Data gathering does NOT stop target CPU
- Halt CPU to see results (stop-time debug)



RunTime Obj View (ROV)

- **Halt to see results**
- **Displays stats about all threads in system**



CPU/Thread Load Graph

- **Analyze time NOT spent in Idle**

Built-in Real-Time Analysis Tools

Logs

- Send DBG Msgs to PC
- Data displayed during stop-time
- Deterministic, low CPU cycle count
- WAY more efficient than traditional `printf()`

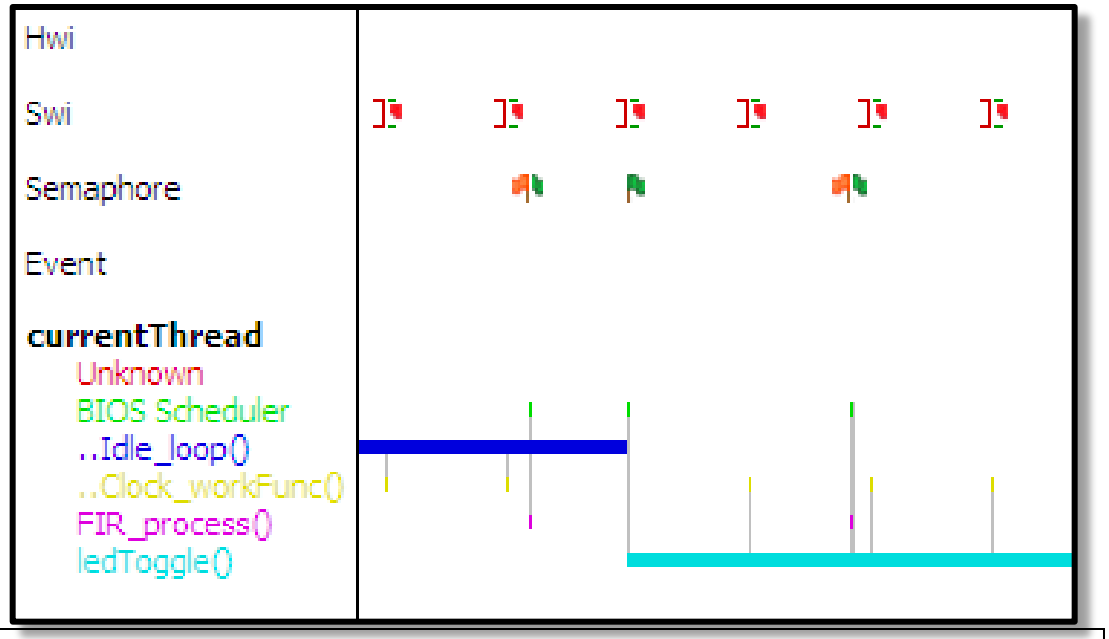
Raw Logs

time	seqID	module	formattedMsg
4,257,279,253	125	Main	"../led.c", line 47: CPU LOAD = [38]
4,257,280,226	126	Main	"../led.c", line 49: TOGGLED LED [42] times
4,357,270,273	127	Main	"../led.c", line 43: BENCHMARK = [3221757] cycles
4,357,271,406	128	Main	"../led.c", line 47: CPU LOAD = [38]
4,357,275,486	129	Main	"../led.c", line 49: TOGGLED LED [43] times
4,457,286,080	130	Main	"../led.c", line 43: BENCHMARK = [3224677] cycles

```
Log_info1("TOGGLED LED [%u] times", count);
```

Execution Graph

- View system events down to the CPU cycle…
- Calculate benchmarks



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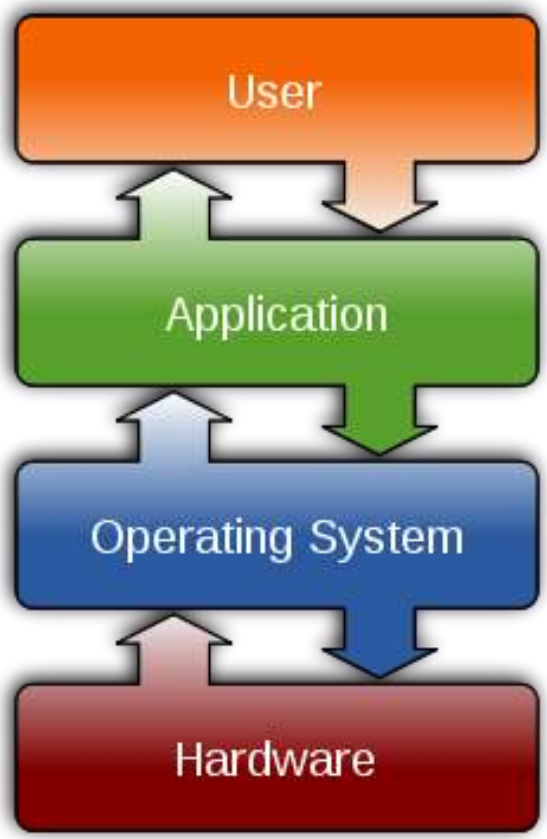
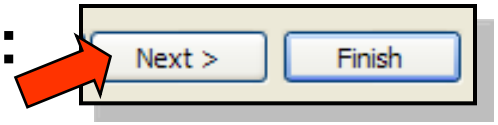
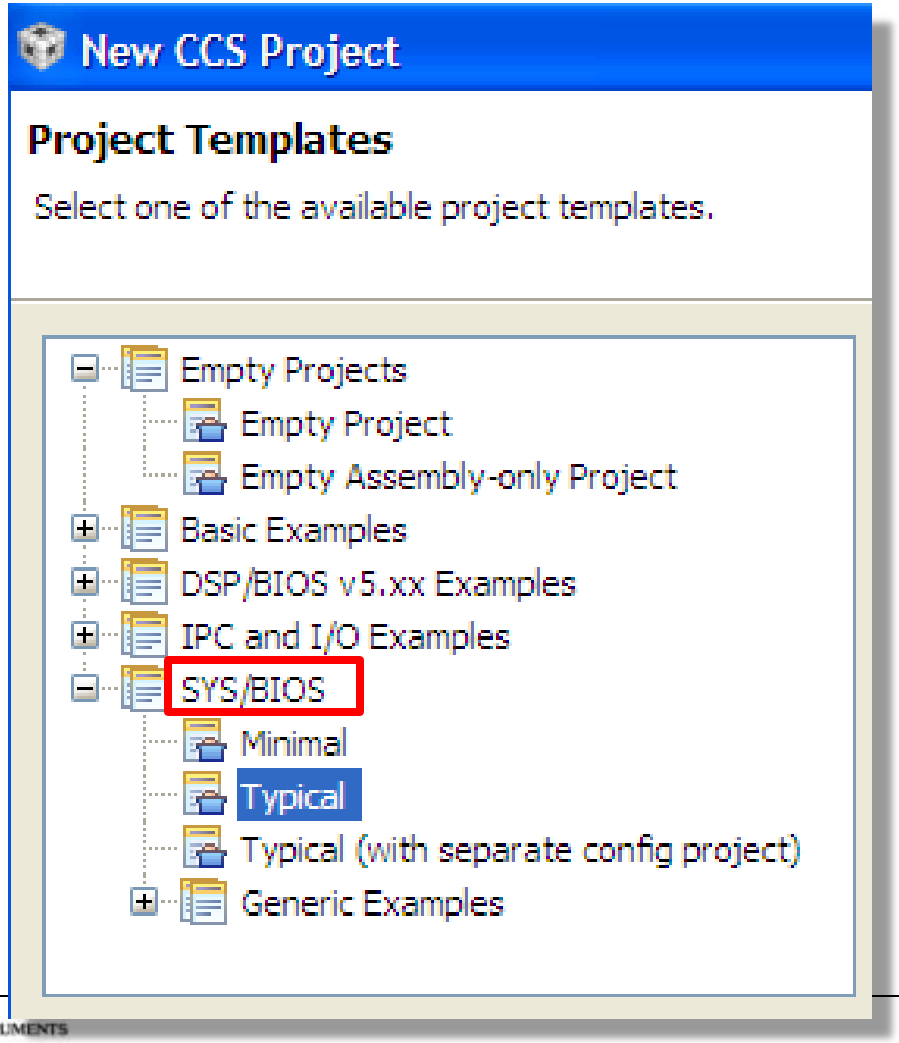


Building a NEW SYS/BIOS Project

- **Create CCS Project (as normal), then click:**



- **Select a SYS/BIOS Example:**

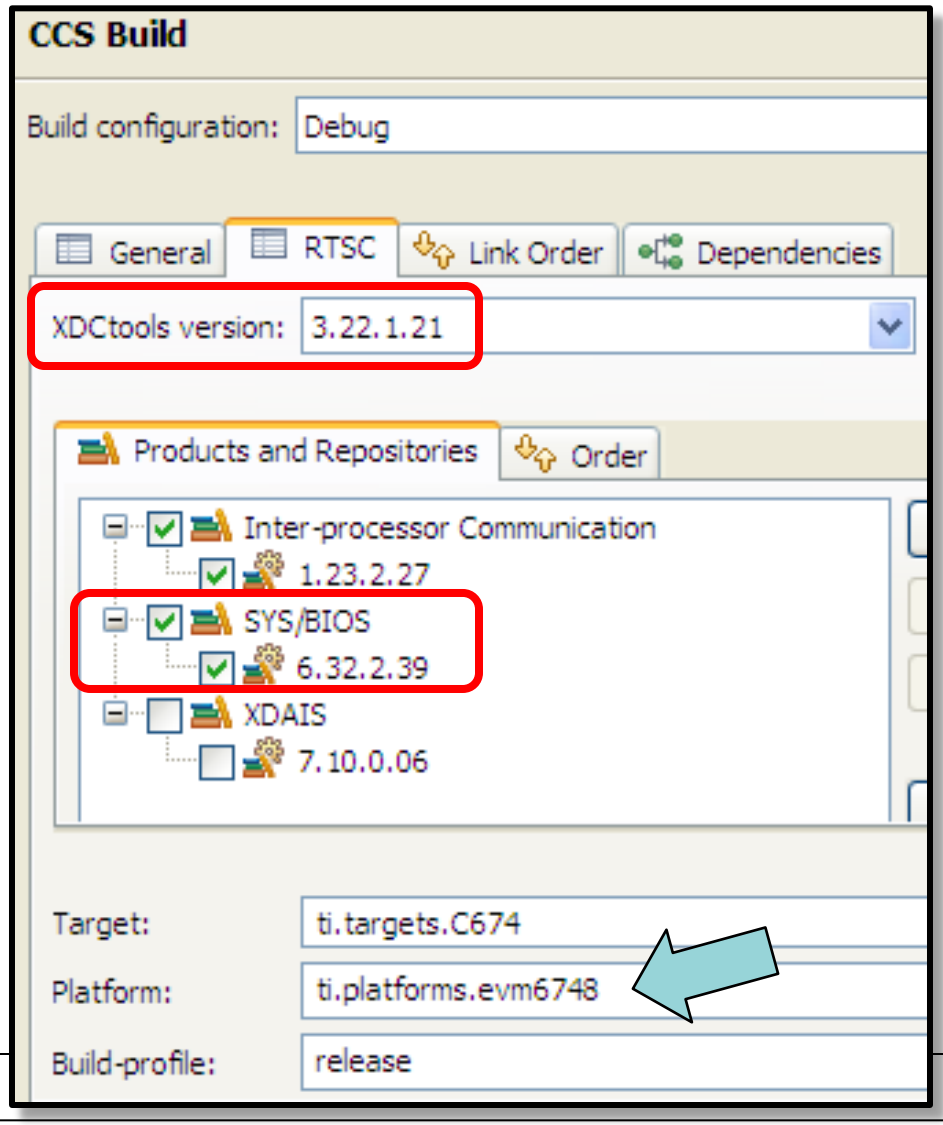


What's in the project created by "Typical"?

- Paths to SYS/BIOS tools
- .CFG file (app.cfg) that contains "typical" configuration for static objects (e.g. Swi, Task…)
- Source files (main.c) that contains appropriate #includes of header files

SYS/BIOS Project Settings

- Select versions for XDC, IPC, SYS/BIOS, xDAIS
- Select “Platform” file (similar to the .tcf seed file for memory)



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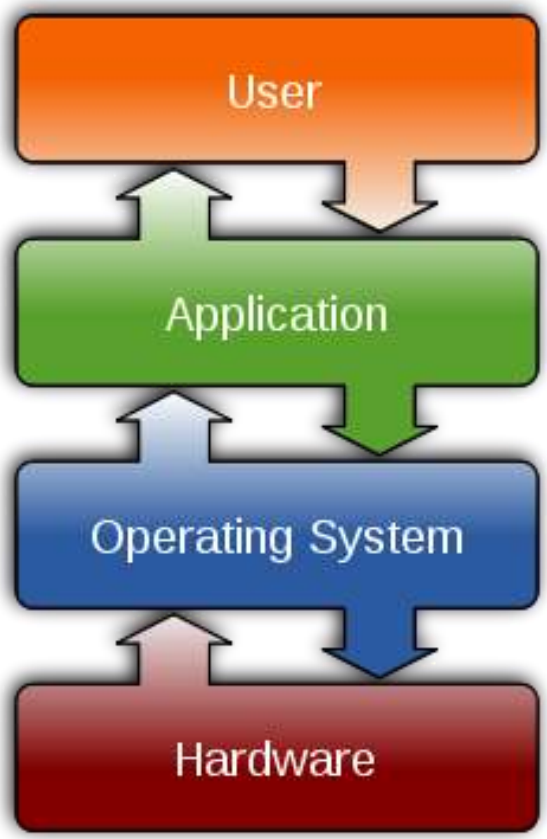
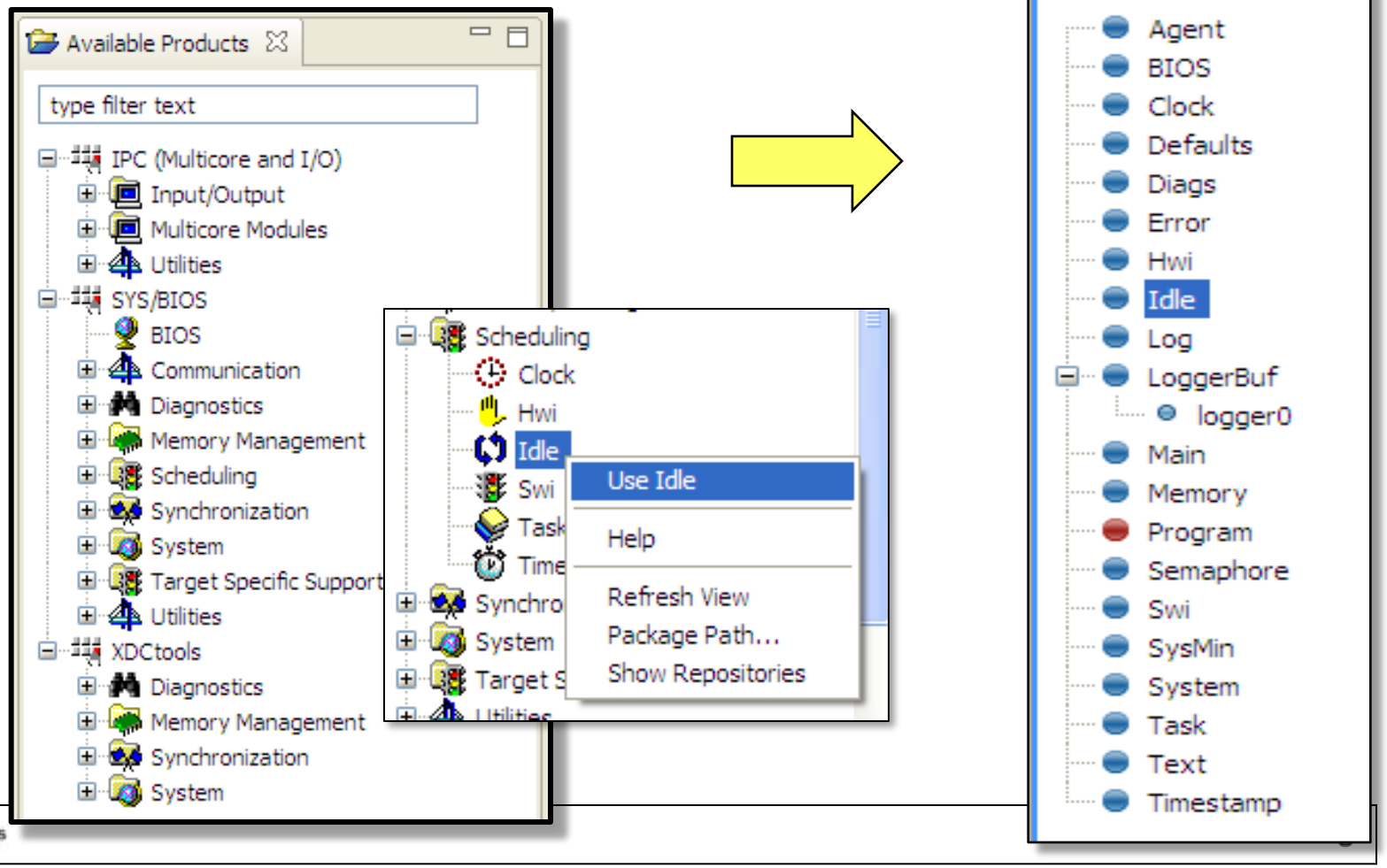


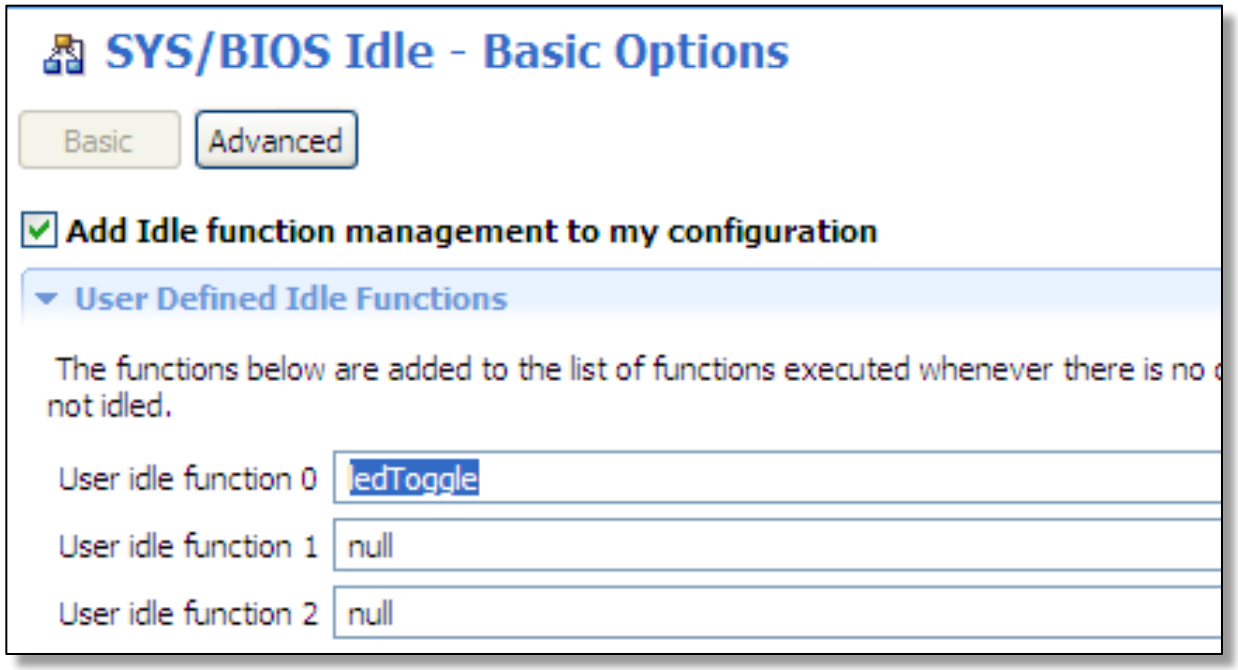
Static BIOS Configuration

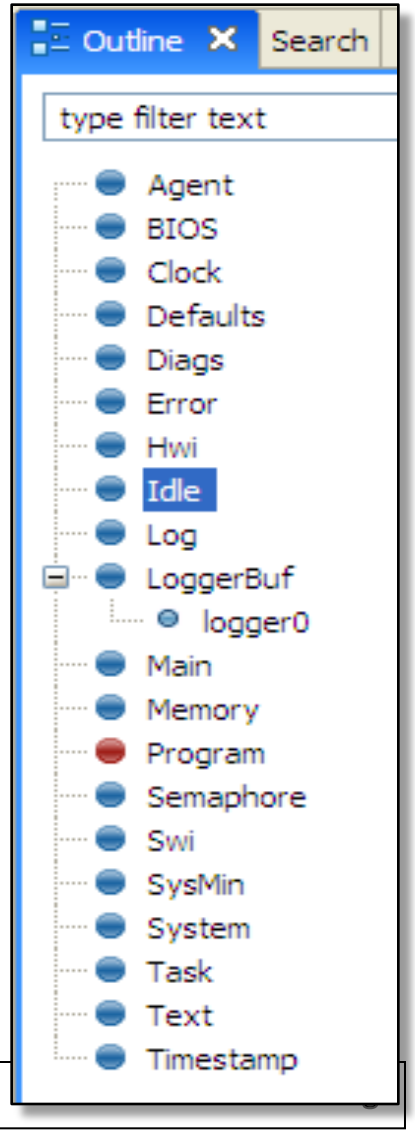
- **Users interact with the CFG file via the GUI – XGCONF:**
  - XGCONF shows “Available Products” – Right-click and “Use Mod”
  - “Mod” shows up in Outline view – Right-click and “Add New”
  - All graphical changes in GUI displayed in .cfg source code



Static Config – .CFG Files

- **Users interact with the CFG file via the GUI – XGCONF:**
  - When you “Add New”, you get a dialogue box to set up parameters
  - Two views: “Basic” and “Advanced”





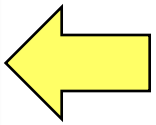
.CFG Files (XDC script)

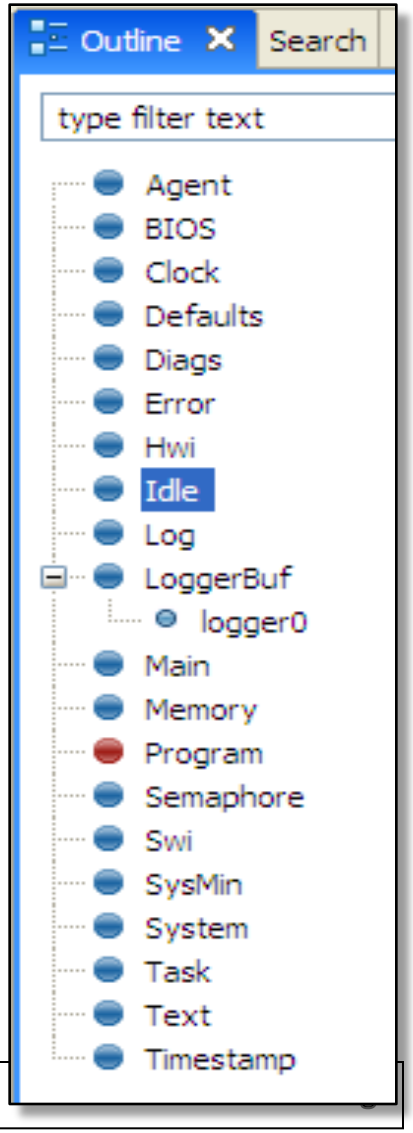
- All changes made to the GUI are reflected with java script in the .CFG file
- Click on a module on the right, see the corresponding script in app.cfg

app.cfg

```
11
12var BIOS = xdc.useModule('ti.sysbios.BIOS');
13var Clock = xdc.useModule('ti.sysbios.knl.Clock');
14var Swi = xdc.useModule('ti.sysbios.knl.Swi');
15var Task = xdc.useModule('ti.sysbios.knl.Task');
16var Semaphore = xdc.useModule('ti.sysbios.knl.Semaphore');
17var Hwi = xdc.useModule('ti.sysbios.hal.Hwi');
18var Idle = xdc.useModule('ti.sysbios.knl.Idle');
19var Timestamp = xdc.useModule('xdc.runtime.Timestamp');
20
```

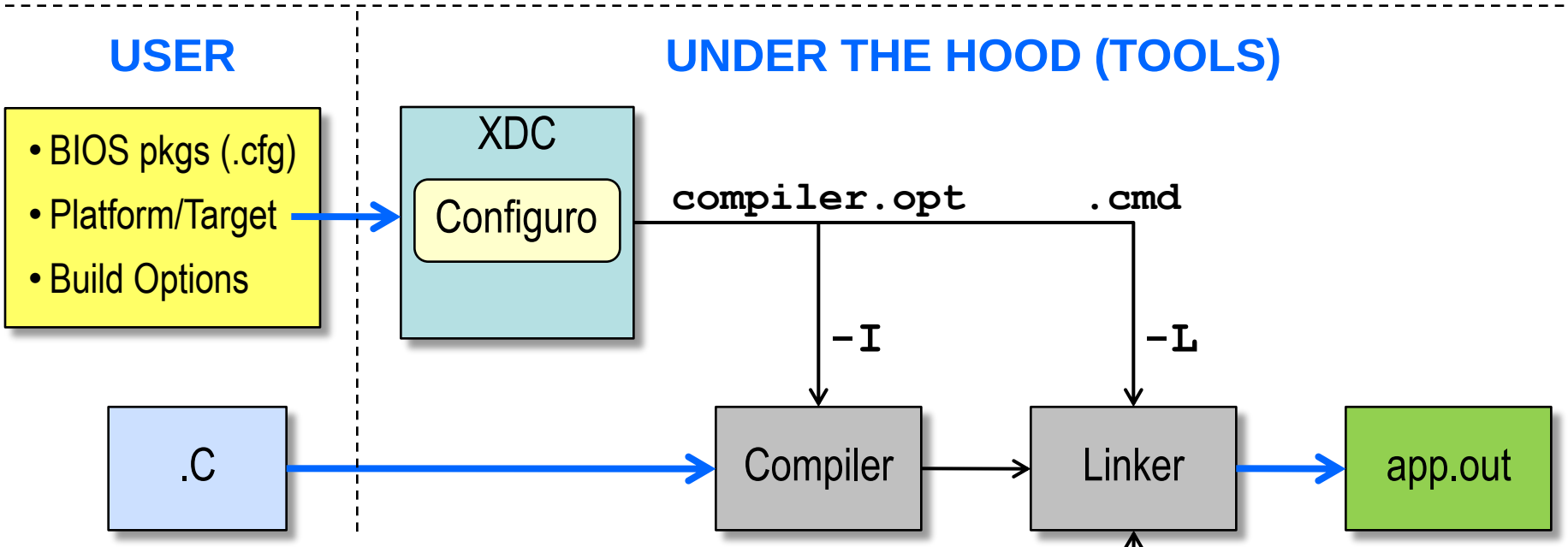
```
98Idle.idleFxns[0] = "&ledToggle";
```





Configuration Build Flow (CFG)

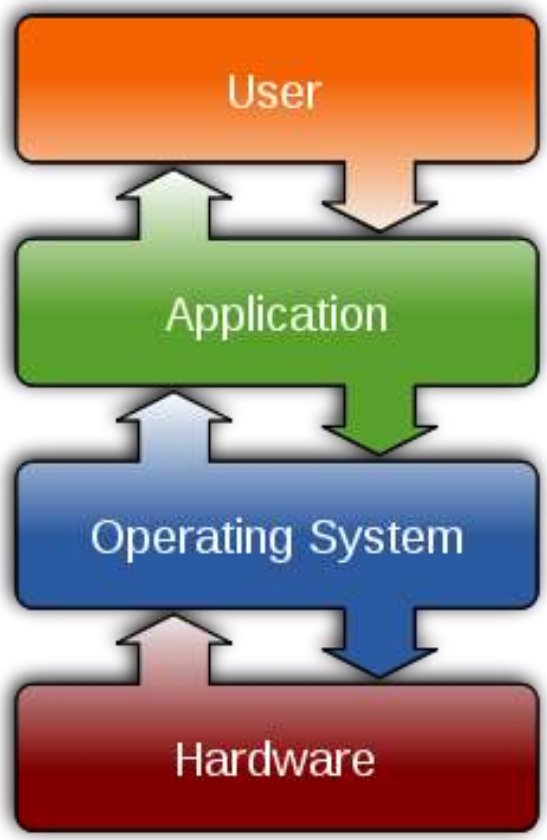
- SYS/BIOS – user configures system with CFG file
- The rest is "under the hood"



- BIOS modules (like HWI, Clock, Semaphore, etc.) are delivered as RTSC compliant packages
- RTSC – Real Time Software Components – Packages that contain libraries and metadata (similar to Java.jar files)
- XDC – eXpress DSP Components – set of tools to consume RTSC packages (knows how to read RTSC metadata)

Outline

- Intro to SYS/BIOS
  - Overview
  - Threads and Scheduling
  - Creating a BIOS Thread
  - System Timeline
  - Real-Time Analysis Tools
  - Create A New Project
  - BIOS Configuration (.CFG)
  - Platforms
  - For More Info…..
- BIOS Threads



Platform (Memory Config)

Memory Config

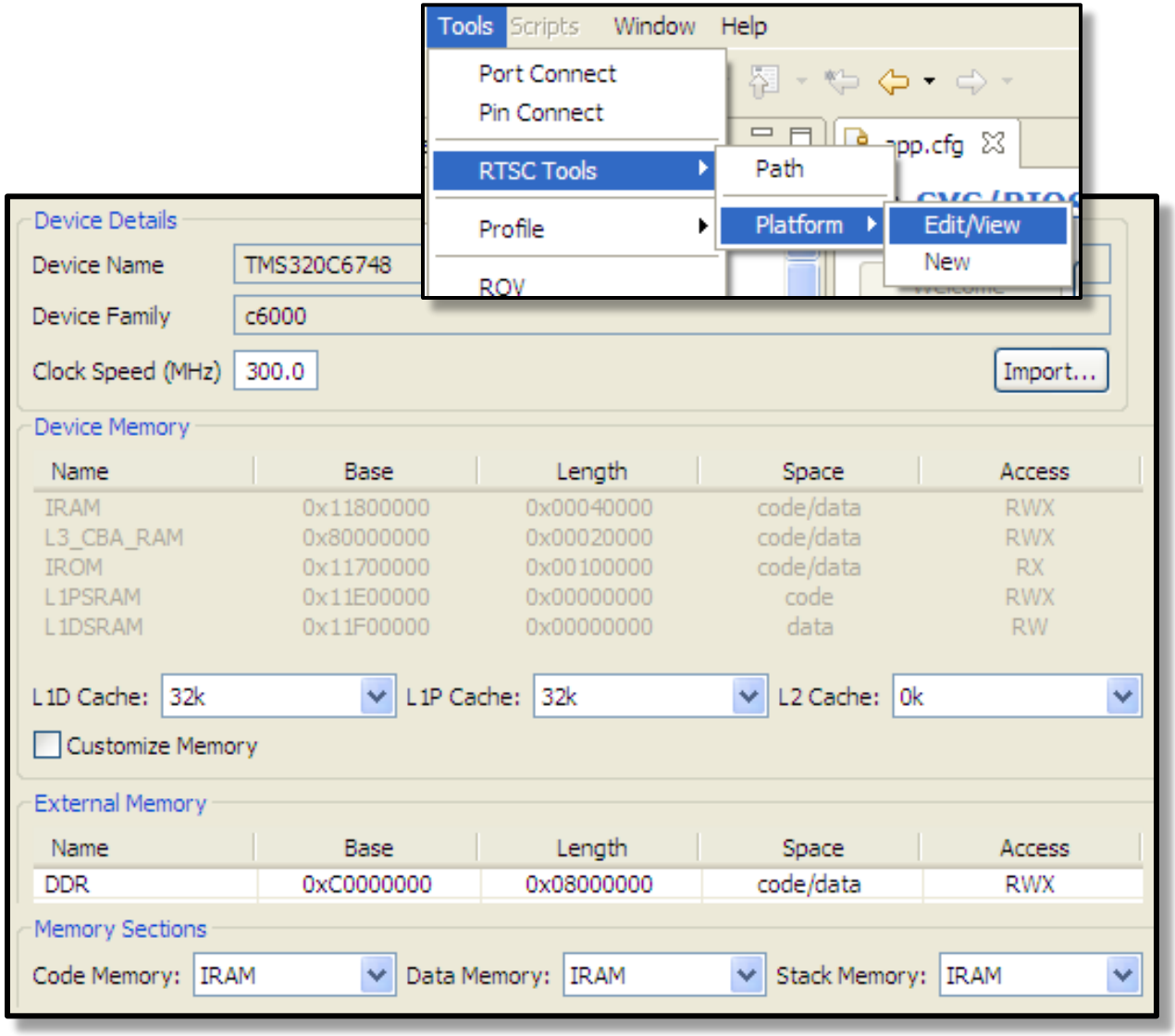
- Create Internal Memory Segments (e.g. IRAM)
- Configure cache
- Define External Memory Segments

Section Placement

- Can link code, data and stack to any defined mem segment

Custom Platform

- Use “Import” button to copy “seed” platform and then customize



Outline

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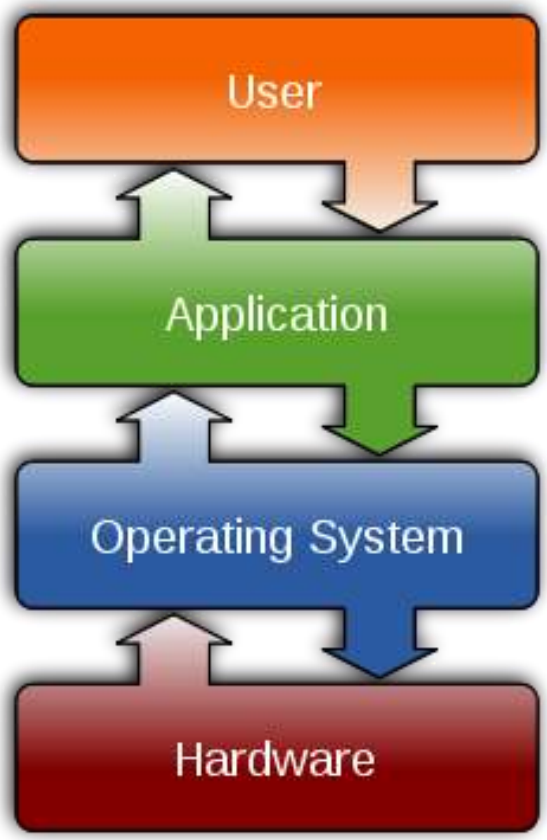
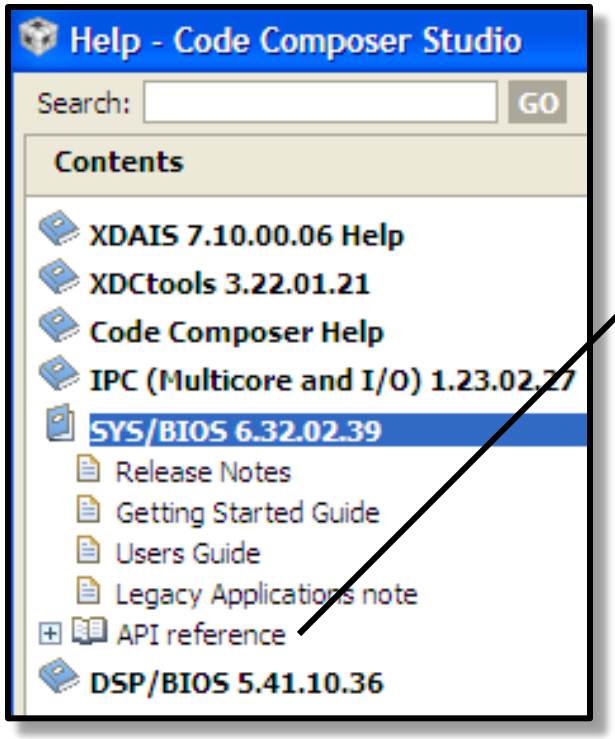


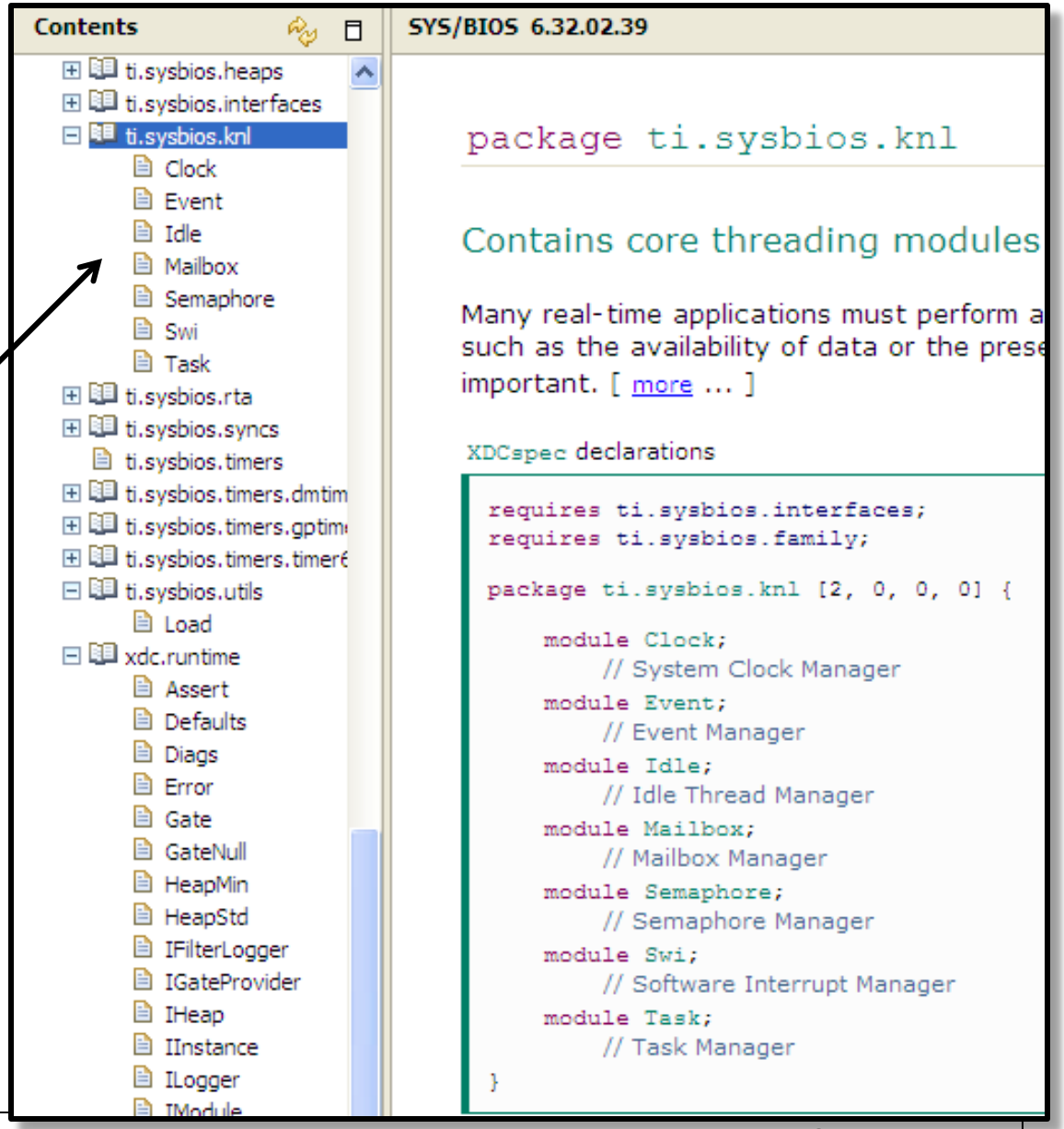
For More Information (1)

- SYS/BIOS Product Page (www.ti.com/sysbios).

For More Information (2)

- **CCS Help Contents**



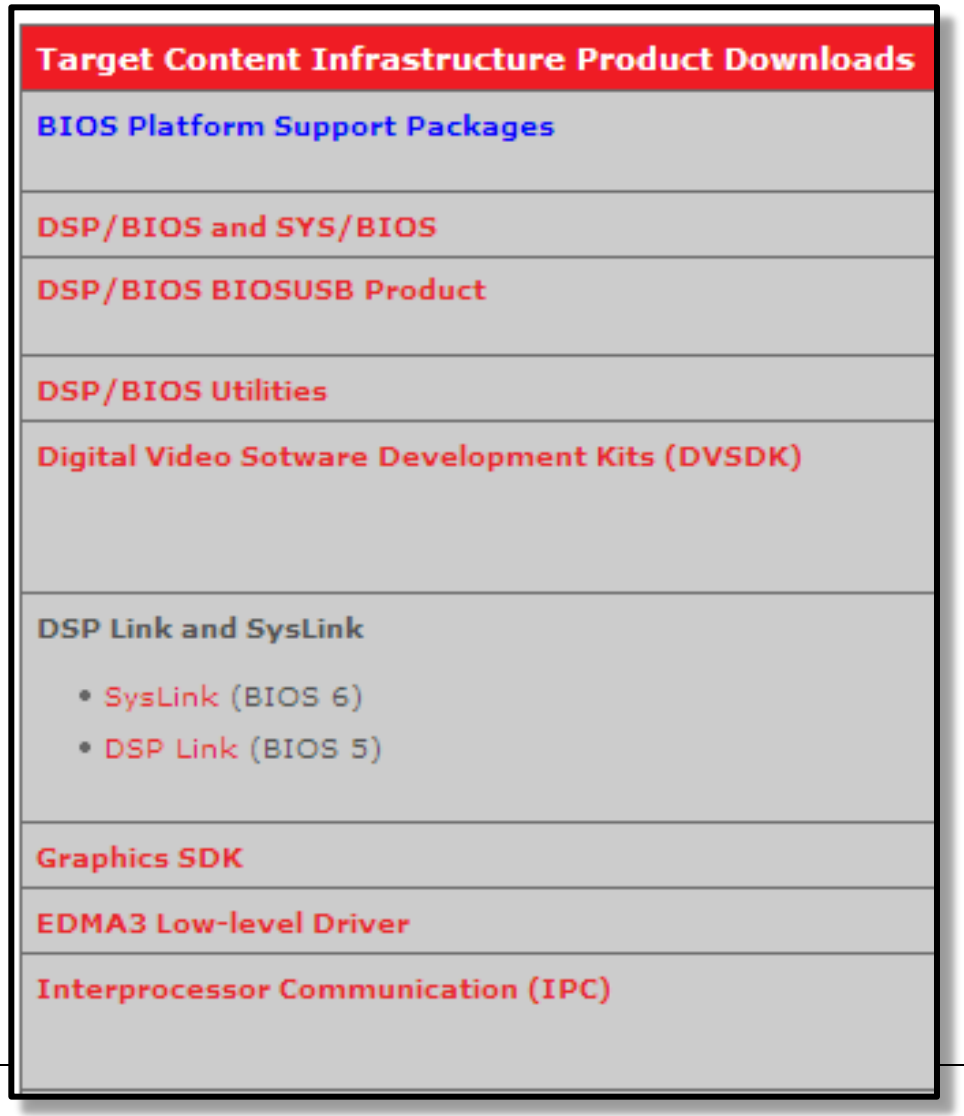


- User Guides
- API Reference (knl)

Download Latest Tools

- **Download Target Content**

http://software-dl.ti.com/dsps/dsps_public_sw/sdo_sb/targetcontent/



- DSP/BIOS
- SYS/BIOS
- Utilities
- SysLink
- DSP Link
- IPC
- Etc.

Outline

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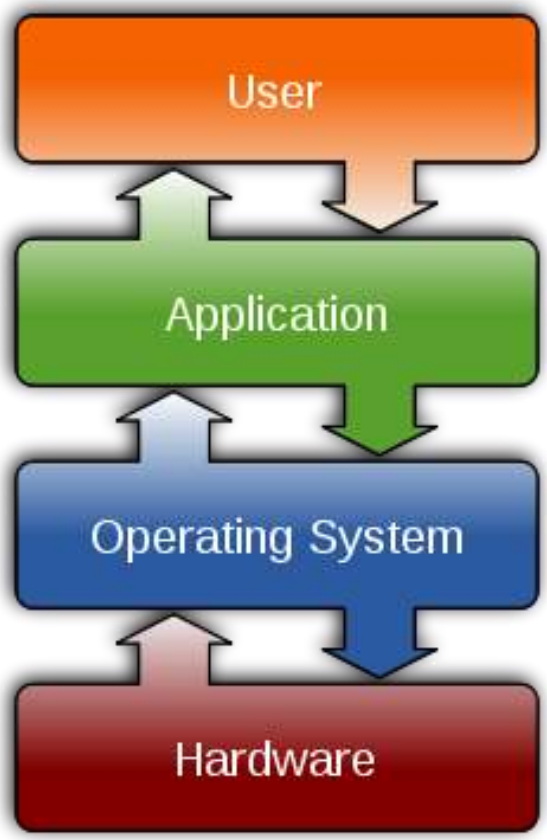


Hwi Scheduling

Hard R/T

Hwi (hi)
Hardware Interrupts

- Hwi priorities set by hardware
- Fixed number, preemption optional

Swi
Software Interrupts

- Up to 32 priority levels (16 on C28x)
- Any number possible, all preemptive

Task
Tasks

- Up to 32 priority levels (16 on C28x)
- Any number possible, all preemptive

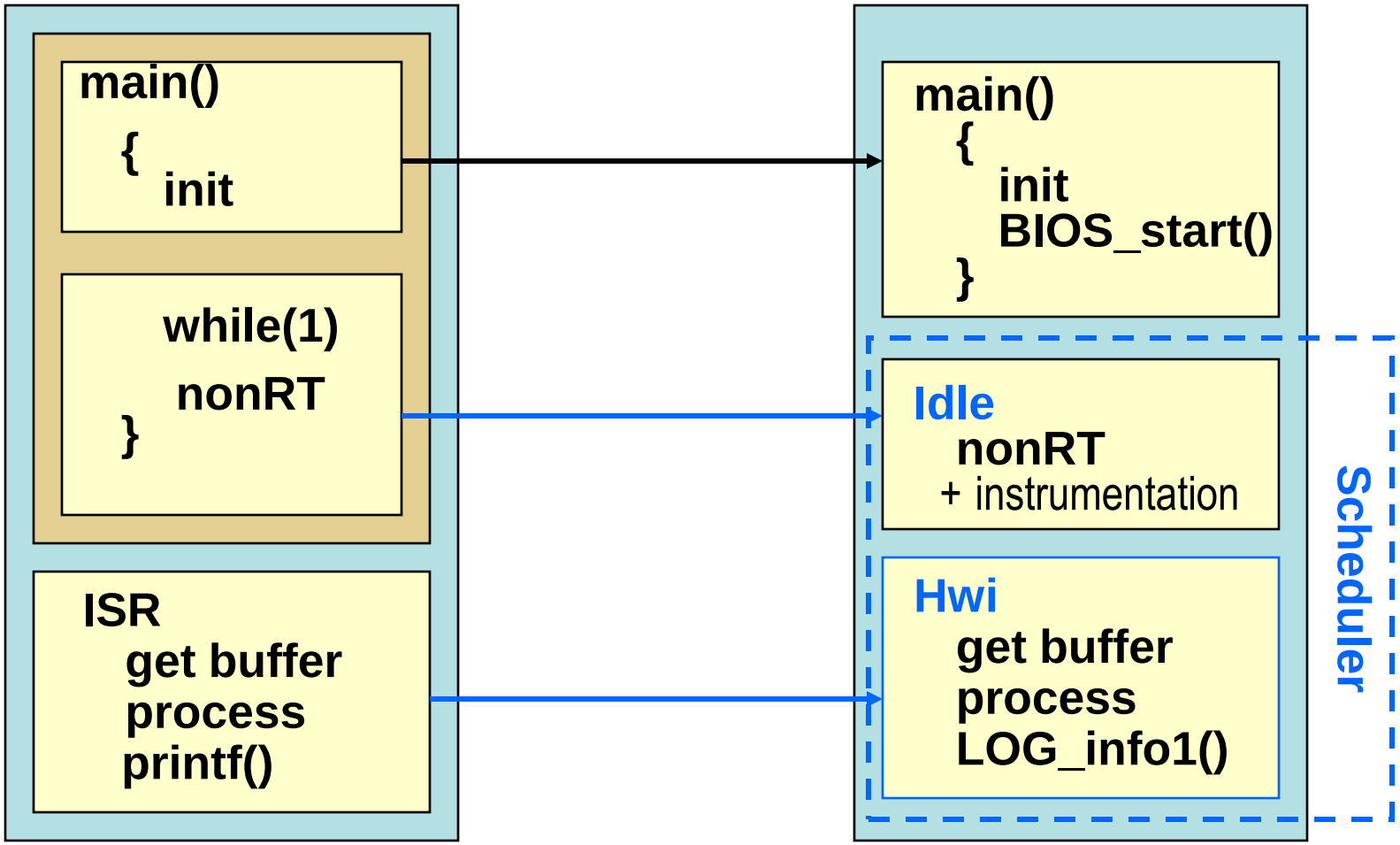
Soft R/T

Idle (lo)
Background

- Continuous loop
- Non-realtime in nature

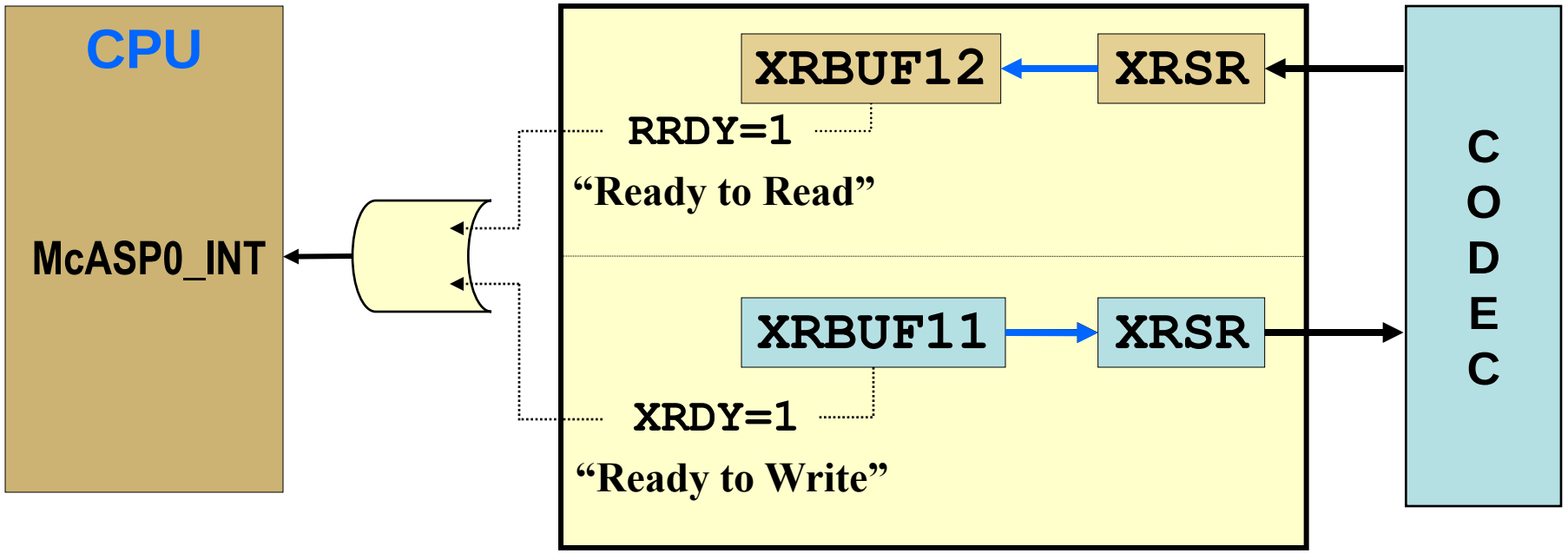
- Idle events run in sequence when no Hwis are posted
- Hwi is ISR with automatic vector table generation + context save/restore
- Any Hwi preempts Idle, Hwi may preempt other Hwi if desired

Foreground / Background Scheduling



- Idle events run in sequence when no Hwis are posted
- Hwi is ISR with automatic vector table generation + context save/restore
- Any Hwi preempts Idle, Hwi may preempt other Hwi if desired

CPU Interrupts from Peripheral (Ex: McASP)



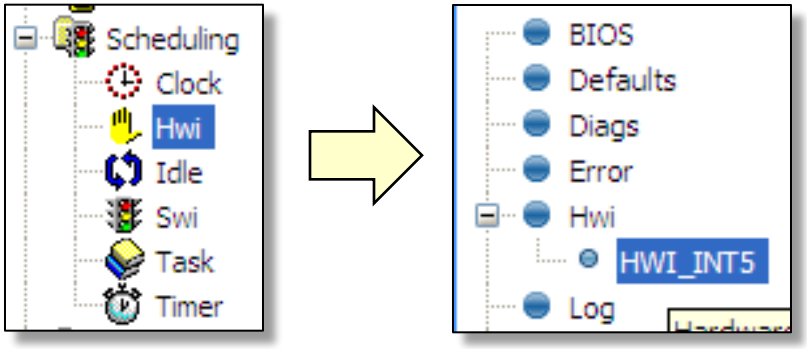
- Peripheral (e.g. McASP on C6748) causes an interrupt to the CPU to indicate "service required".
- This "event" will have an ID (datasheet) and can be tied to a specific CPU interrupt (target specific)

How do we configure SYS/BIOS to respond to this interrupt and call the appropriate ISR?

Configuring an *Hwi* – Statically via GUI

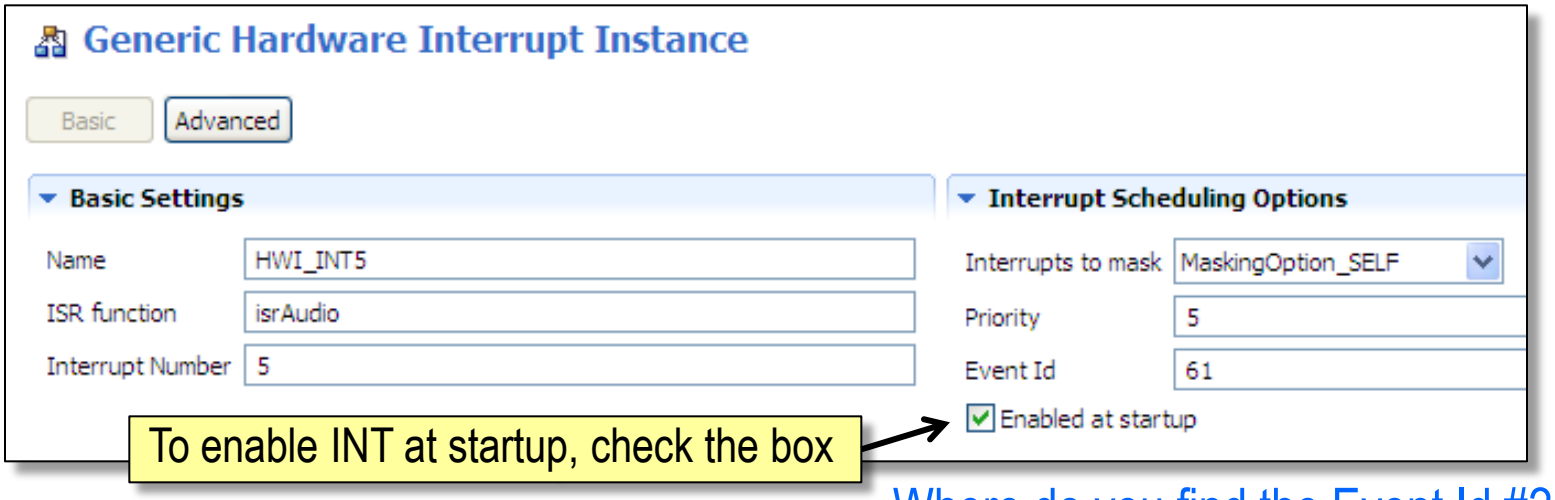
Example: Tie McASP0_INT to the CPU's HWI_5

1 Use Hwi module *(Available Products)*, insert new Hwi *(Outline View)*



Remember, BIOS objects can be created via the GUI, script code or C code (dynamic)

2 Configure Hwi – Event ID, CPU Int #, ISR vector:



To enable INT at startup, check the box

Where do you find the Event Id #?

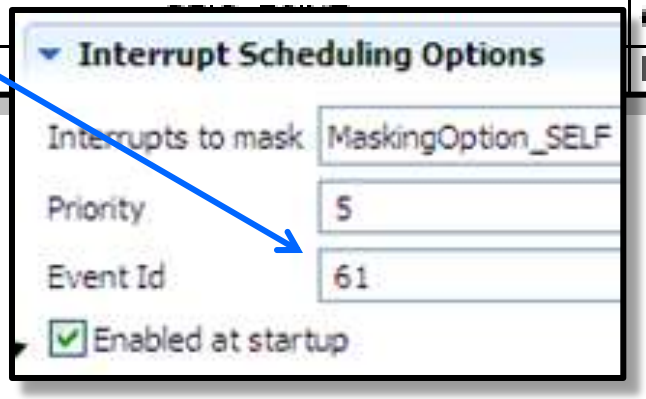
Hardware Event IDs

- So, how do you know the names of the interrupt events and their corresponding event numbers?

  Look it up (in the datasheet), of course…

Ref: TMS320C6748 datasheet (exerpt):

59	GPIO_B5INT	GPIO Bank 5 Interrupt
60	DDR2_MEMERR	DDR2 Memory Error Interrupt
61	MCASP0_INT	McASP0 Combined RX/TX Interrupts
62		GPIO Bank 6 Interrupt
63		RTC Combined

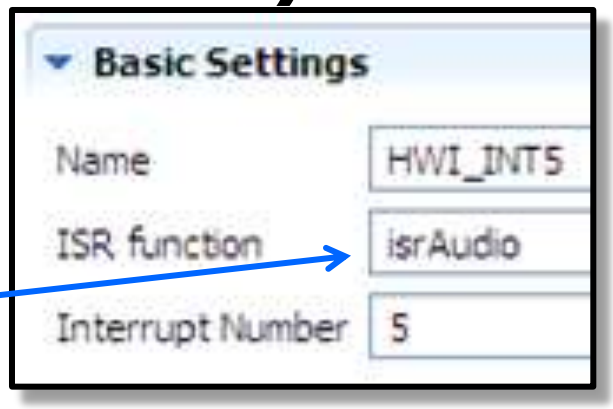


- This example is target-specific for the C6748 DSP. Simply refer to your target's datasheet for similar info.

  What happens in the ISR ?

Example ISR (McASP)

Example ISR for MCASP0_INT interrupt



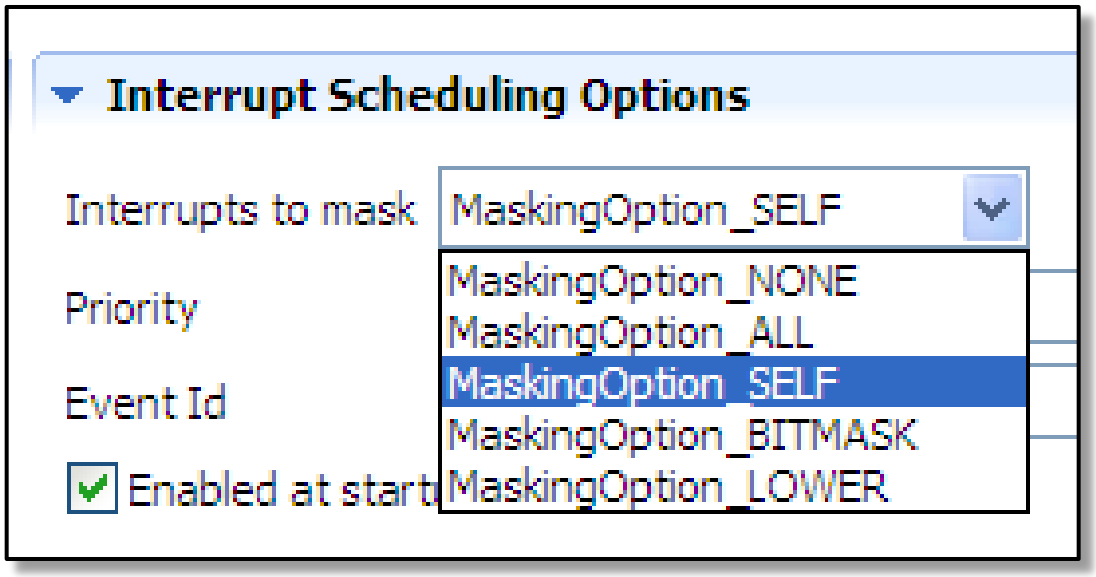
isrAudio:

```
pInBuf[blkCnt] = MCASP1->RCV;    // READ audio sample from McASP
MCASP->XMT = pOutBuf[blkCnt]     // WRITE audio sample to McASP
blkCnt+=1;                       // increment blk counter


if( blkCnt >= BUFFSIZE )
{
   memcpy(pOut, pIn, Len);       // Copy pIn to pOut (Algo)
   blkCnt = 0;                   // reset blkCnt for new buf's
   pingPong ^= 1;                // PING/PONG buffer boolean
}
```

Can one interrupt preempt another?

Enabling Preemption of Hwi



- **Default** mask is "SELF" – which means all other Hwi's can pre-empt except for itself
- Can choose other masking options as required:

ALL:	Best choice if ISR is short & fast
NONE:	Dangerous – make sure ISR code is re-entrant
BITMASK:	Allows custom mask
LOWER:	Masks any interrupt(s) with lower priority (ARM)

SYS/BIOS Hwi APIs

Other useful Hwi APIs:

`Hwi_disableInterrupt()`
`Hwi_enableInterrupt()`
`Hwi_clearInterrupt()`
	Set enable bit = 0
	Set enable bit = 1
	Clear INT flag bit = 0

`Hwi_post()` New in SYS/BIOS	Post INT # (in code)

`Hwi_disable()`
`Hwi_enable()`
`Hwi_restore()`
	Global INTs disable
	Global INTs enable
	Global INTs restore

Let's move on to SWIs...

Outline

- Intro to SYS/BIOS
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  - Software Interrupts (SWI)
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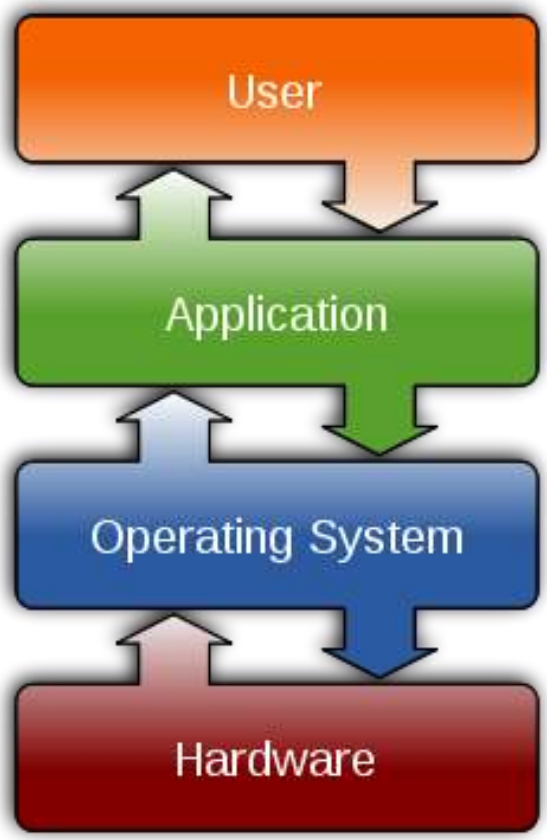
  - Semaphores (SEM)



Swi Scheduling

Hard R/T

Hwi (hi)
Hardware Interrupts

- Hwi priorities set by hardware
- Fixed number, preemption optional

Swi
Software Interrupts

- **Up to 32 priority levels (16 on C28x)**
- **Any number possible, all preemptive**

Task
Tasks

- Up to 32 priority levels (16 on C28x)
- Any number possible, all preemptive

Soft R/T

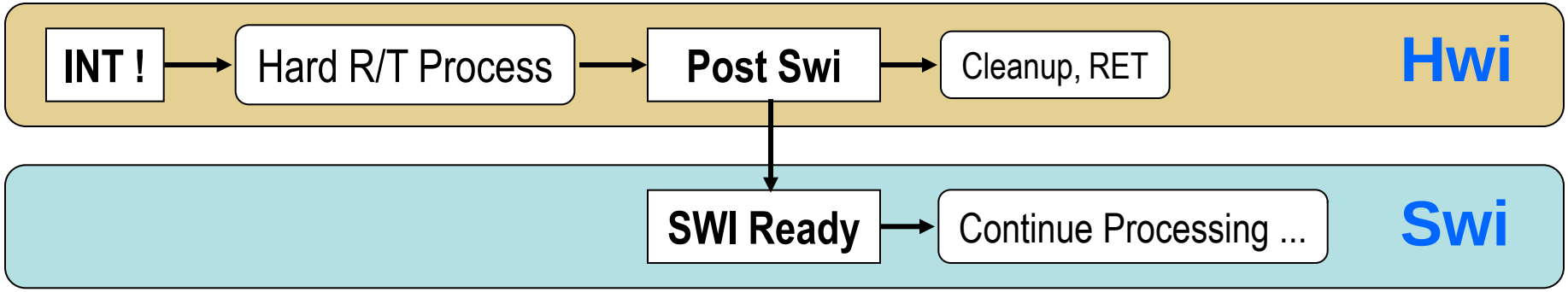
Idle (lo)
Background

- Continuous loop
- Non-realtime in nature

- SYS/BIOS provides for Hwi and Swi management
- SYS/BIOS allows the Hwi to post a Swi to the ready queue

Hardware and Software Interrupt System

Execution flow for flexible real-time systems:



Hwi

- Fast response to INTs
- Min context switching
- High priority for CPU
- Limited # of Hwi possible

isrAudio:

```
*buf++ = *XBUF;
cnt++;
if (cnt >= BLKSZ) {
    Swi_post(swiFir);
    count = 0;
    pingPong ^= 1;
}
```

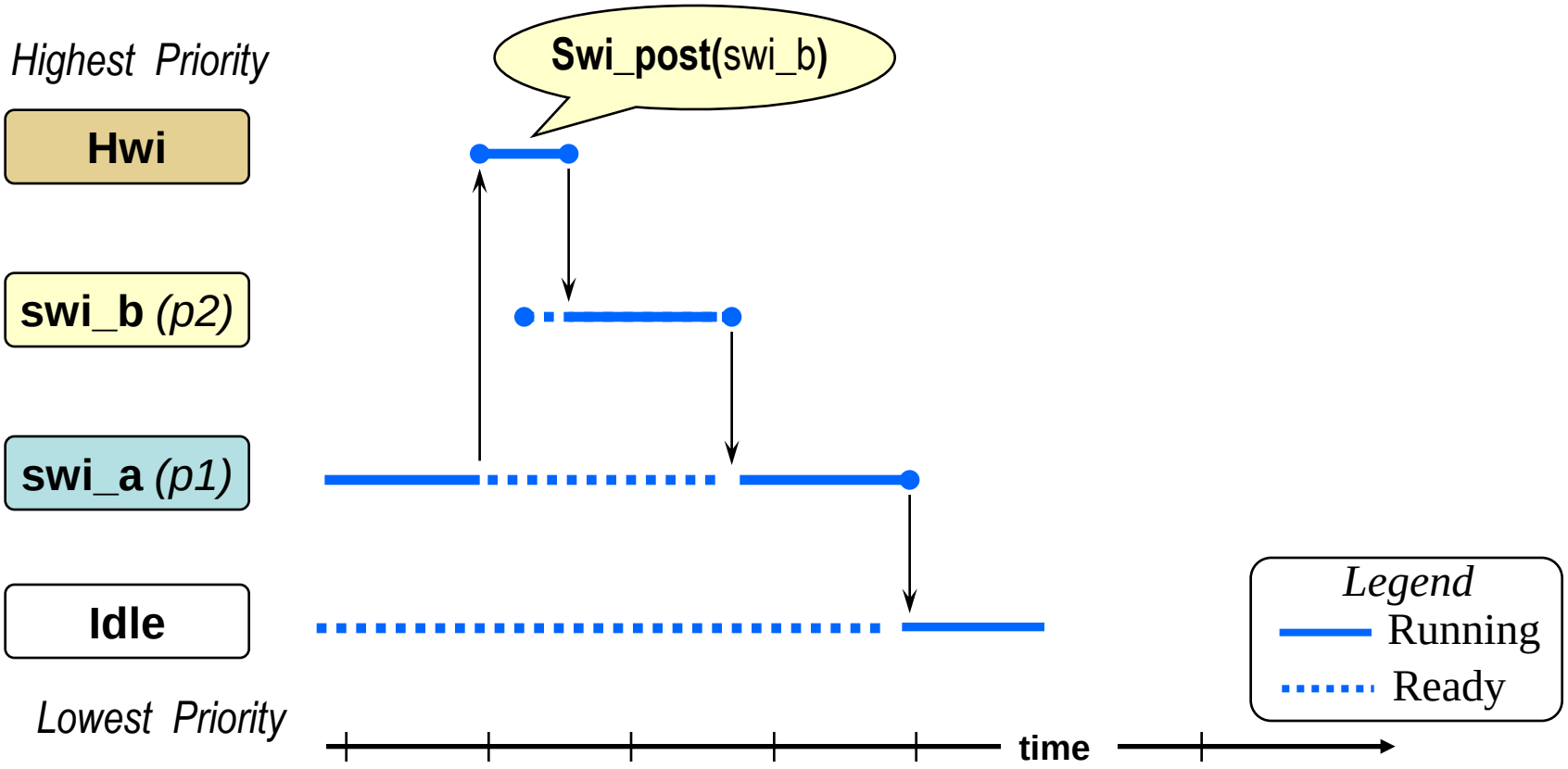
Swi

- Latency in response time
- Context switch
- Selectable priority levels
- Scheduler manages execution

- SYS/BIOS provides for Hwi and Swi management
- SYS/BIOS allows the Hwi to post a Swi to the ready queue

Scheduling SWIs...

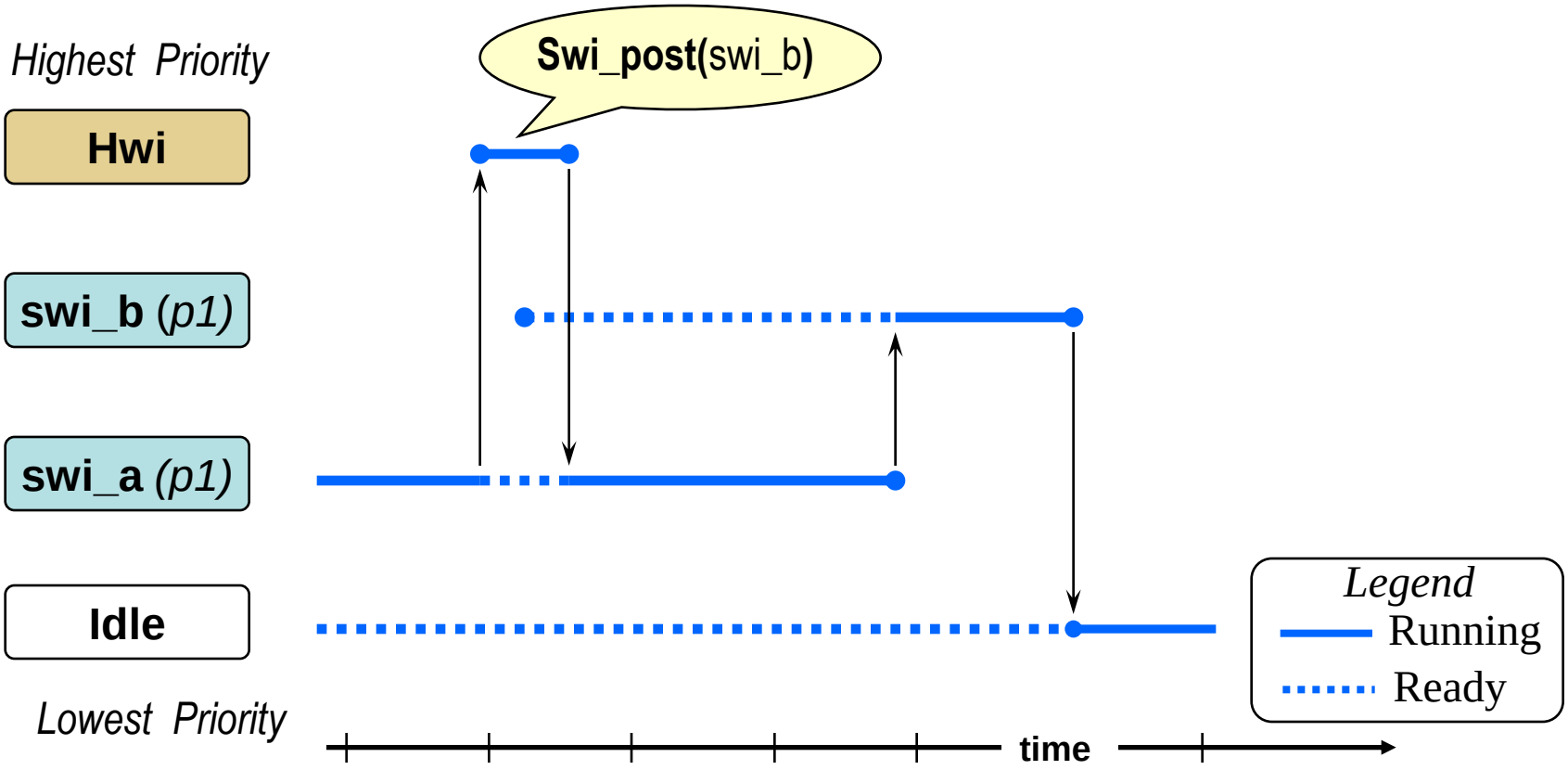
Scheduling Rules



- ***Swi_post(mySwi)*** : Unconditionally post a software interrupt (in the ready state)
- If a higher priority thread becomes ready, the running thread is preempted
- **Swi** priorities from 1 to 32 (C28x has 16)
- Automatic context switch (uses system stack)

What if the SWIs are at the same priority?

Scheduling Rules



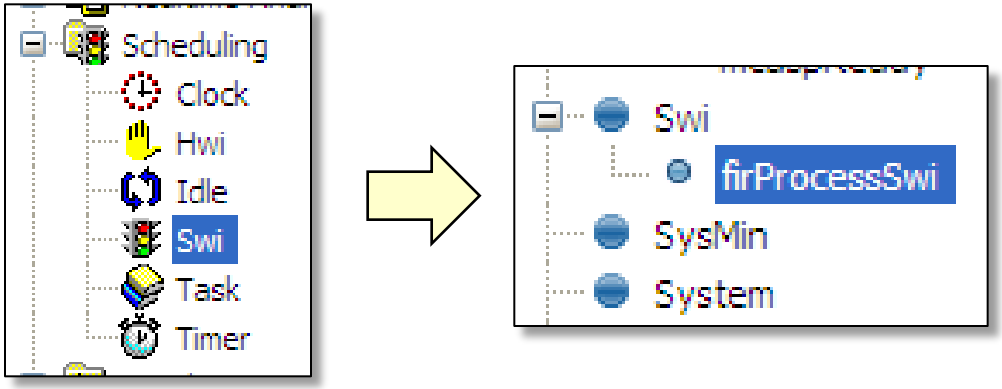
- Processes of same priority are scheduled first-in first-out (FIFO)
- Having threads at the SAME priority offers certain advantages – such as resource sharing (without conflicts)

How do you configure a SWI?

Configuring a *Swi* – Statically via GUI

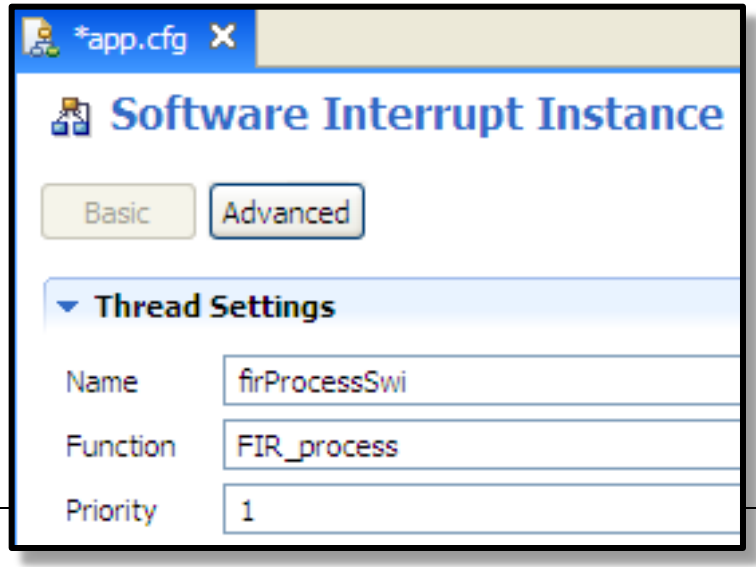
Example: Tie isrAudio() fxn to Swi, use priority 1

1 Use Swi module *(Available Products)*, insert new Hwi *(Outline View)*



Remember, BIOS objects can be created via the GUI, script code or C code (dynamic)

2 Configure Swi – Object name, function, priority:



Let's move on to Tasks...

SYS/BIOS Swi APIs

Other useful Swi APIs:

`Swi_inc()`	Post, increment count
`Swi_dec()`	Decrement count, post if 0
`Swi_or()`	Post, OR bit (signature)
`Swi_andn()`	ANDn bit, post if all posted
`Swi_getPri()`	Get any Swi Priority
`Swi_enable`	Global Swi enable
`Swi_disable()`	Global Swi disable
`Swi_restore()`	Global Swi restore

Let's move on to Tasks...

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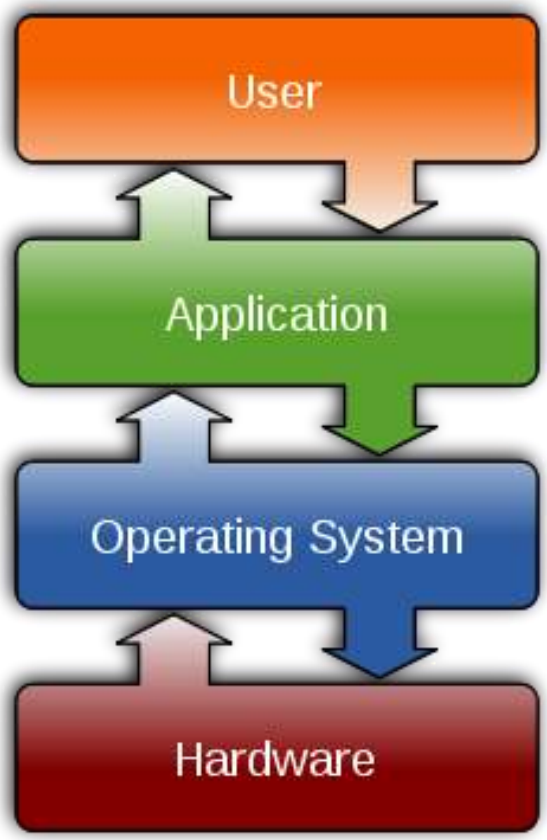

Task Scheduling

Hard R/T

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- Fixed number, preemption optional

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Software Interrupts

- Up to 32 priority levels (16 on C28x)
- Any number possible, all preemptive

Task
Tasks

- **Up to 32 priority levels (16 on C28x)**
- **Any number possible, all preemptive**

Soft R/T

Idle (lo)
Background

- Continuous loop
- Non-realtime in nature

- All Tasks are preempted by all Swi and Hwi
- All Swi are preempted by all Hwi
- Preemption amongst Hwi is determined by user
- In absence of Hwi, Swi, and Task, Idle functions run in loop

Task Code Topology – Pending

```
Void taskFunction(…)
{

/* Prolog */

    while ('condition'){

        Semaphore_pend()

        /* Process */

    }

/* Epilog */

}
```

- **Initialization** (runs once only)
- **Processing** loop – (optional: *cond*)
- Wait for resources to be available
- Perform desired algo work...
- **Shutdown** (runs once - at most)

- Task can encompass *three* phases of activity
- Semaphore can be used to signal resource availability to Task
- `Semaphore_pend()` *blocks* Task until semaphore (flag) is posted

Let's compare/contrast Swi & Task…

Swi vs. Task

Swi

```
_post→ void mySwi () {
       // set local env

          *** RUN ***

       }
```

- "Ready" when *POSTED*
- Initial state NOT preserved – must set each time **Swi** is run
- CanNOT block (runs to completion)
- Context switch speed (~140c)
- All **Swi's** share system stack w/Hwi
- Use: as follow-up to Hwi and/or when memory size is an absolute premium

Task

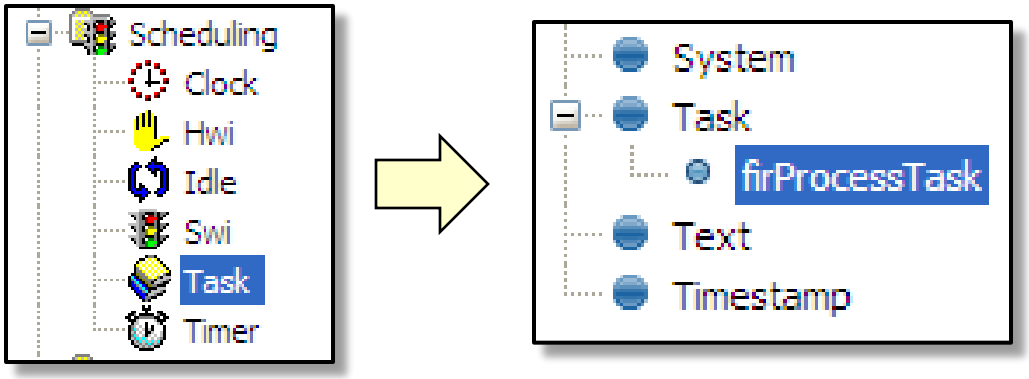
```
_create→void myTask () {
          // Prologue (set Task env)
          while(cond){
              Semaphore_pend();
              *** RUN ***
          }
          // Epilogue (free env)
       }
```

- "Ready" when *CREATED* (BIOS_start or dynamic)
- P-L-E structure handy for resource creation (P) and deletion (E), initial state preserved
- Can block/suspend on semaphore (flag)
- Context switch speed (~160c)
- Uses its OWN stack to store context
- Use: Full-featured sys, CPU w/more speed/mem

Configuring a *Task* – Statically via the GUI

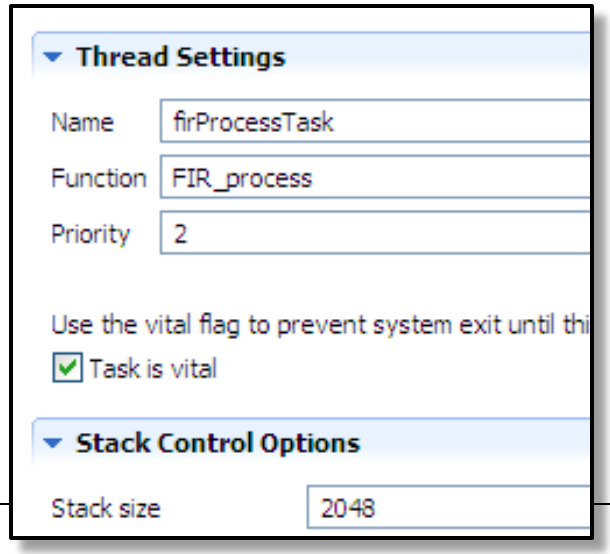
Example: **Create `firProcessTask`, tie to `FIR_process()`, priority 2**

1 Use Task module *(Available Products)*, insert new Task *(Outline View)*



Remember, BIOS objects can be created via the GUI, script code or C code (dynamic)

2 Configure Task – Object name, function, priority, stack size:



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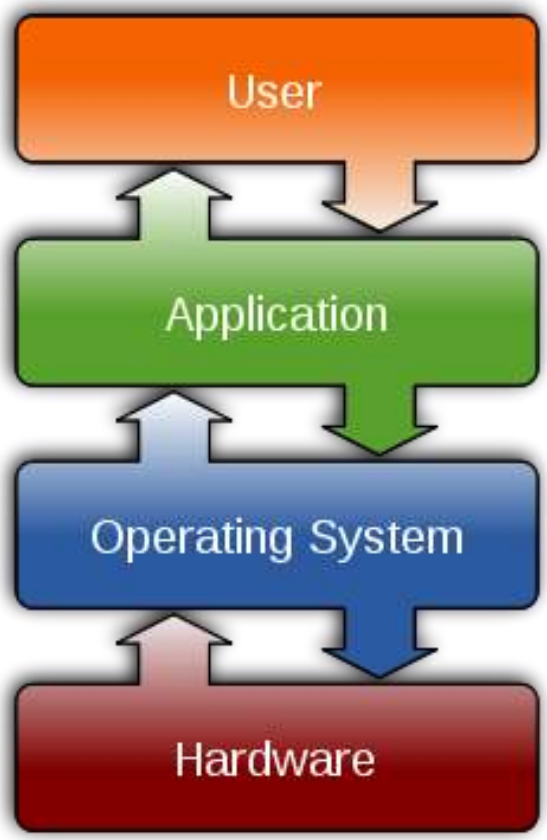
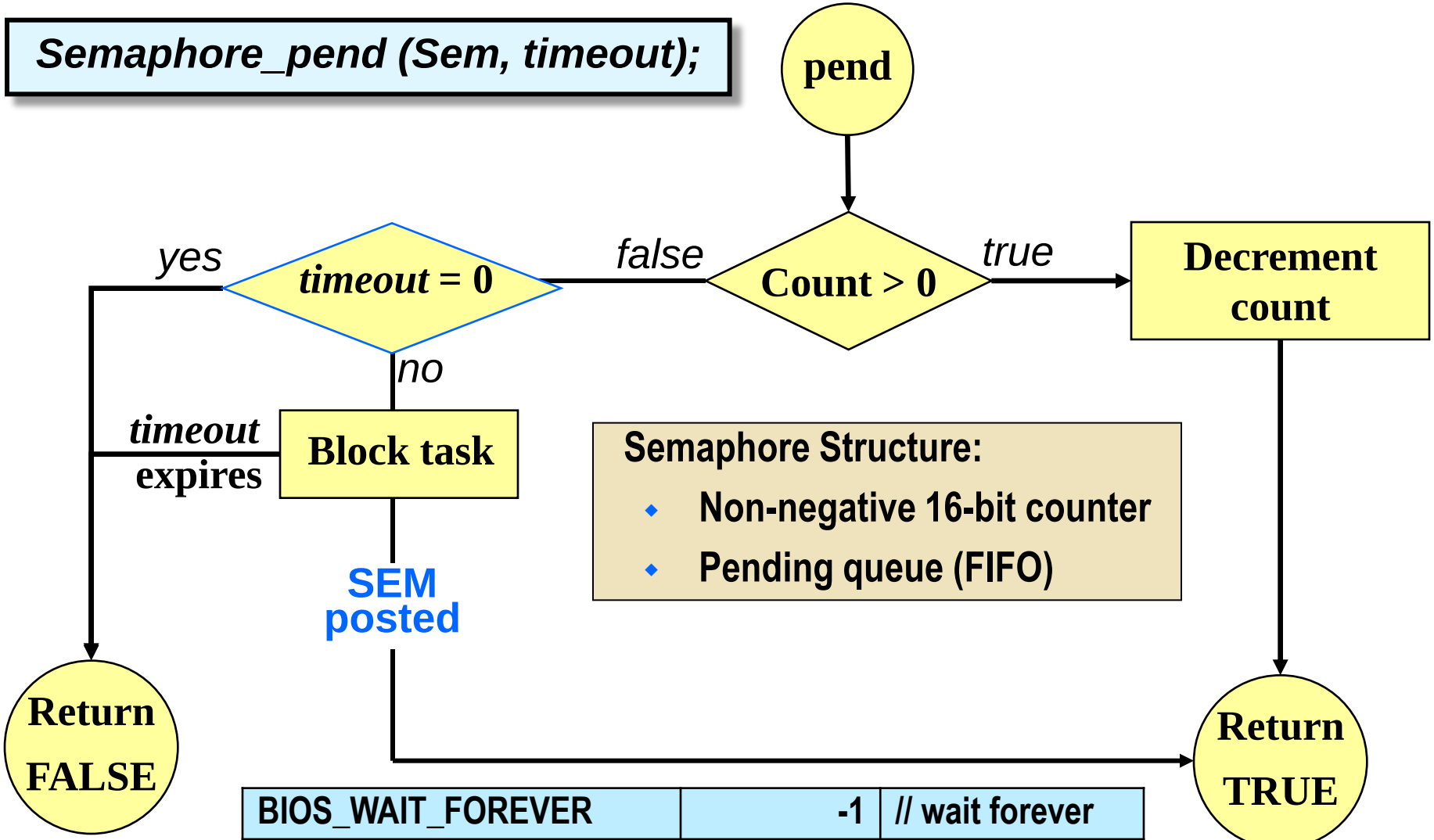
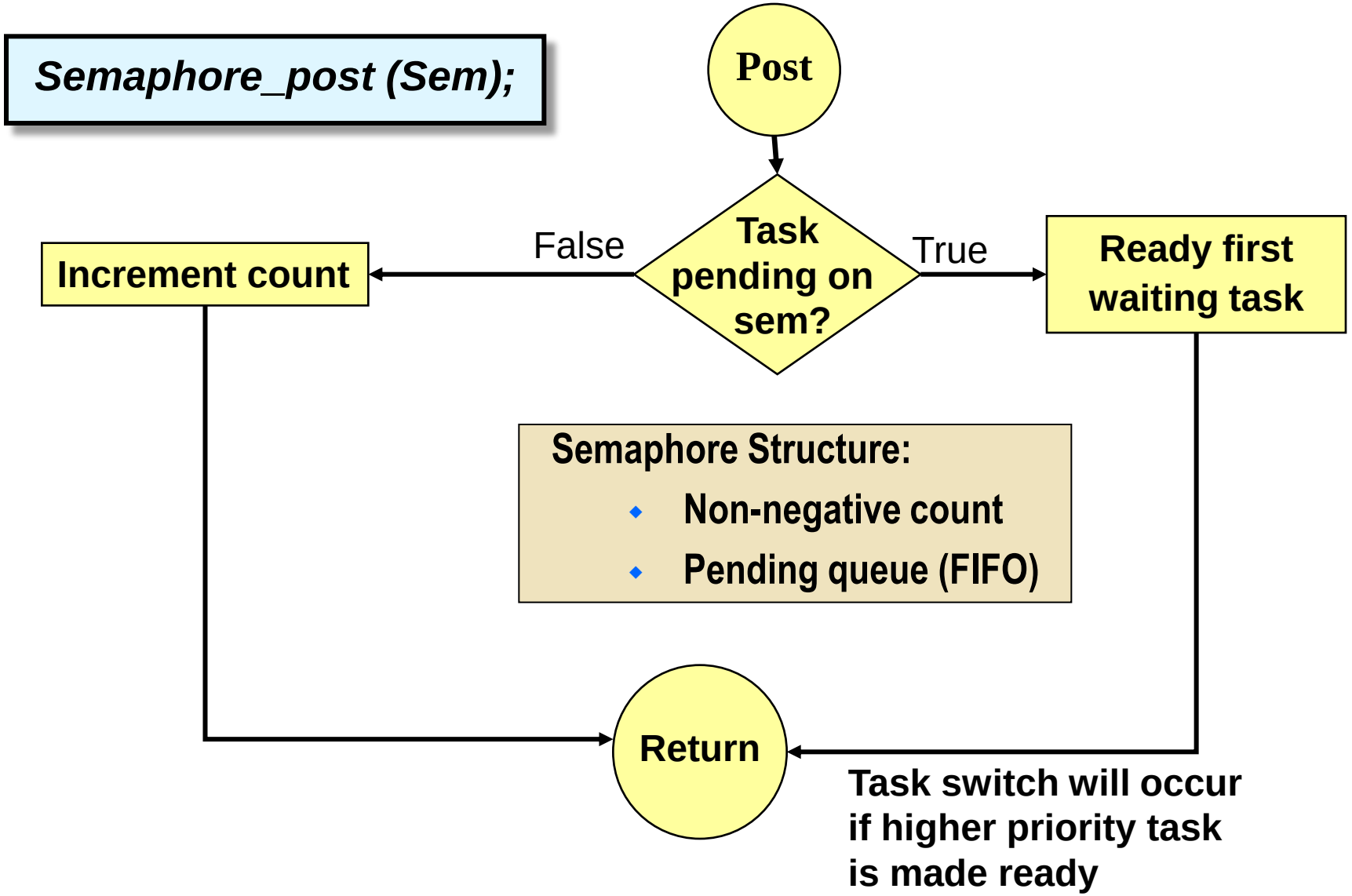


Semaphore Pend



BIOS_WAIT_FOREVER	-1	// wait forever
Zero	0	// don't wait
value	timeout	// system ticks

Semaphore Post

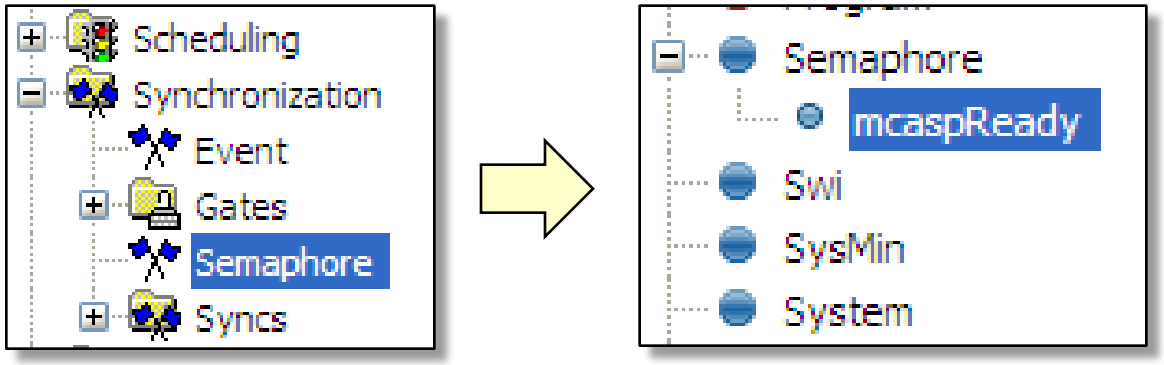


How do you configure a Semaphore?

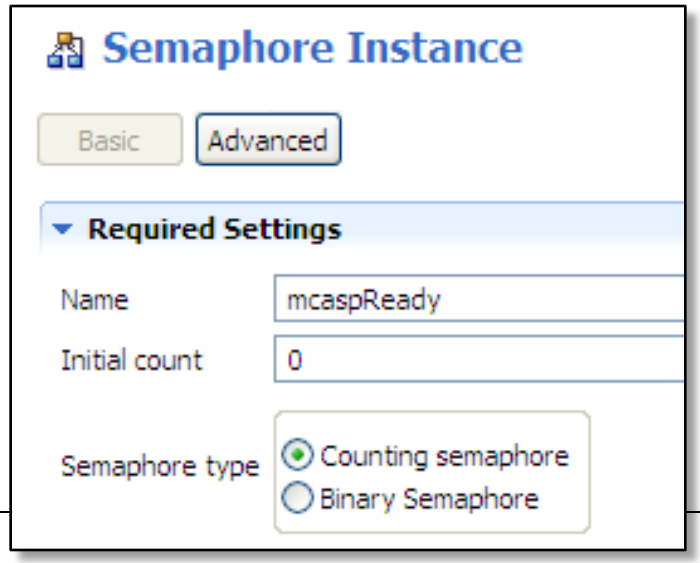
Configuring a *Semaphore* – Statically via GUI

Example: Create mcaspReady, counting

1 **Use Semaphore** *(Available Products)* **, insert new Semaphore** *(Outline View)*



2 **Configure Semaphore – Object name, initial count, type:**



SYS/BIOS Semaphore/Task APIs

Other useful Semaphore APIs:

`Semaphore_getCount()`	Get semaphore count

Other useful Task APIs:

`Task_sleep()`	Sleep for N system ticks
`Task_yield()`	Yield to same pri Task
`Task_setPri()`	Set Task priority
`Task_getPri()`	Get Task priority
`Task_get/setEnv()`	Get/set Task Env
`Task_enable()`	Enable Task Mgr
`Task_disable()`	Disable Task Mgr
`Task_restore()`	Restore Task Mgr

Questions?