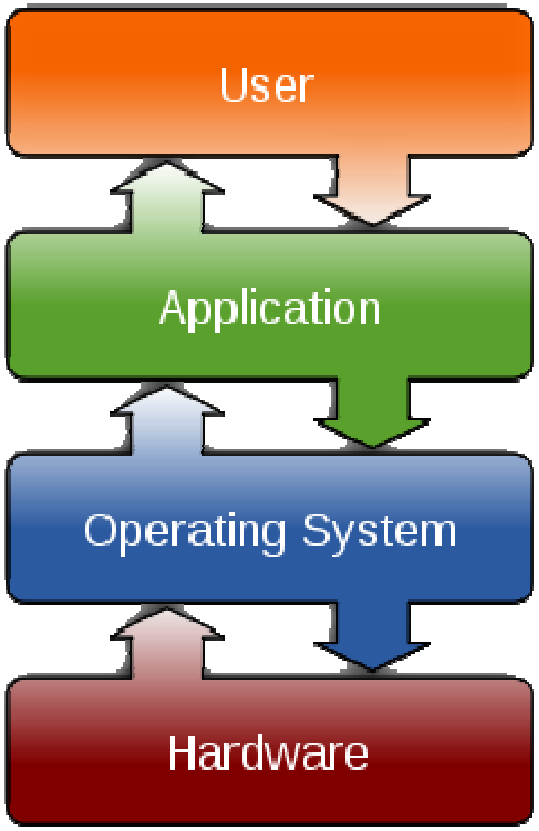
Introduction to SYS/BIOS

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 Information
- **BIOS Threads**



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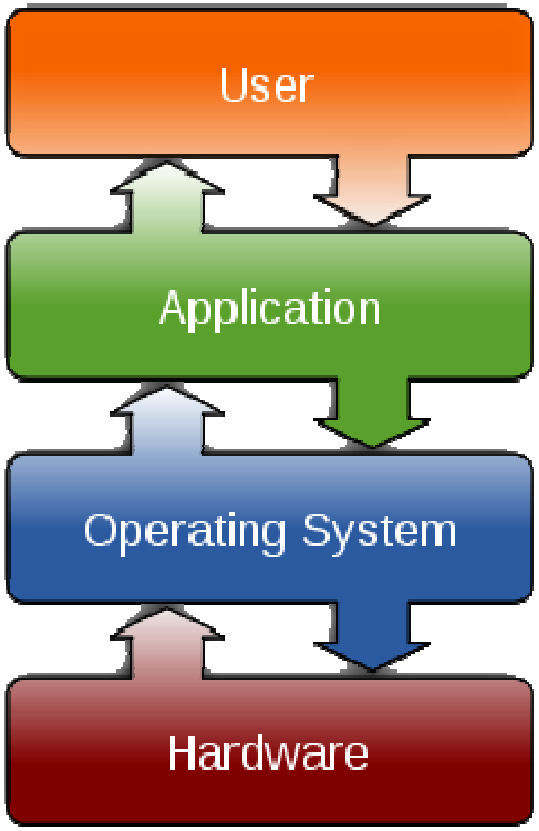
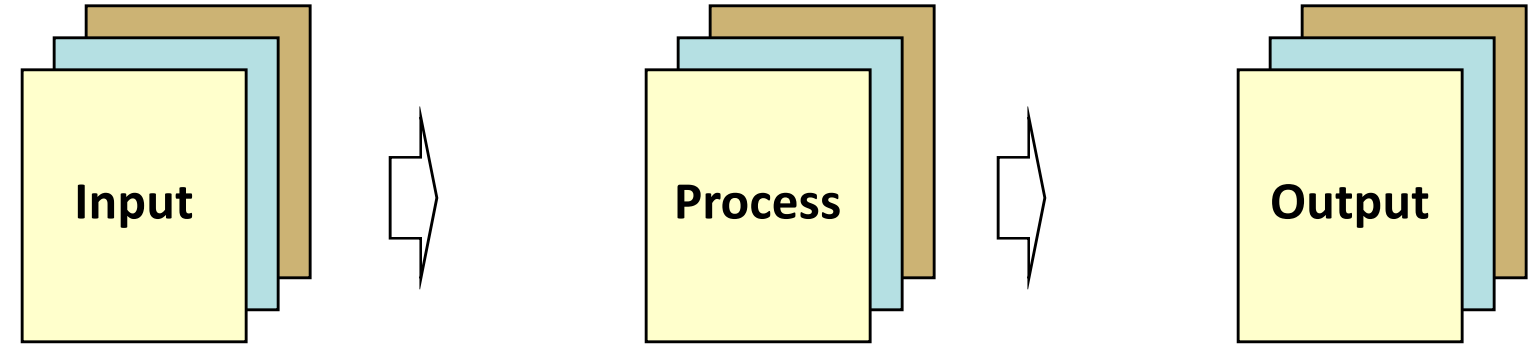
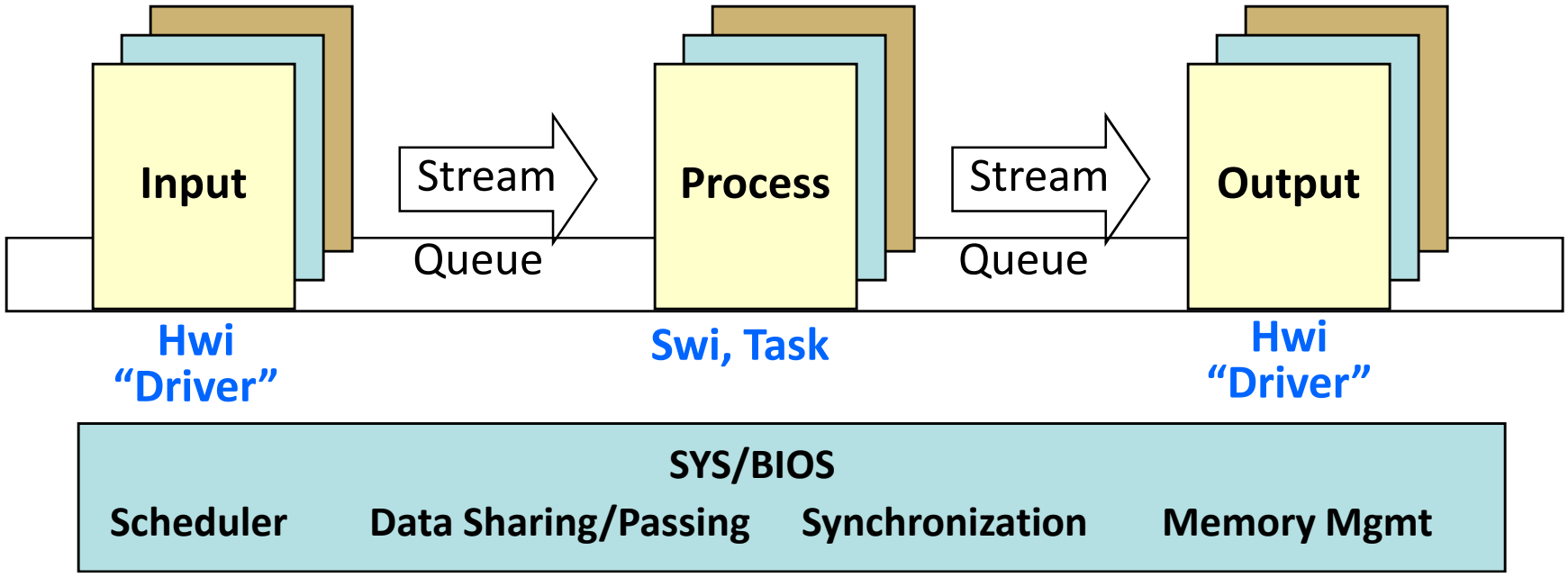


Need for an Operating System



- 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 ?
- Two 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?

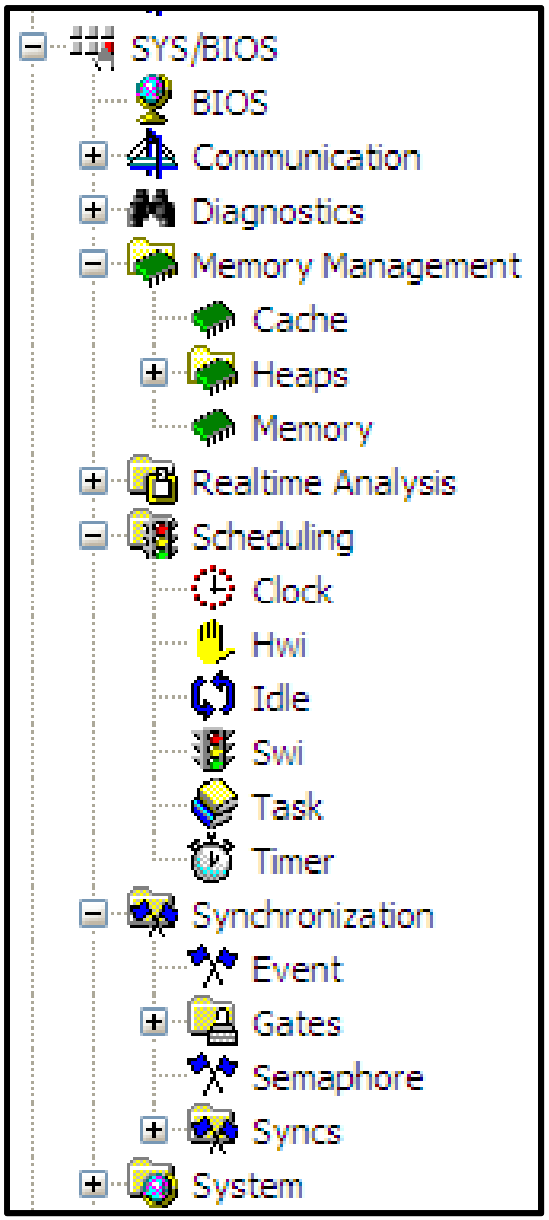
SYS/BIOS Overview



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 – Include only what is needed**
- **API - 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**

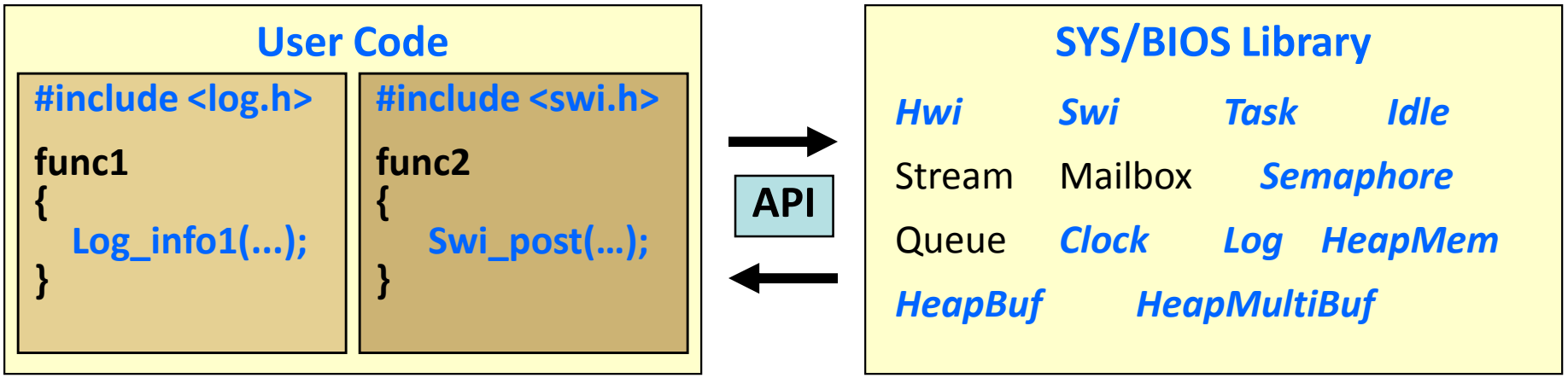
SYS/BIOS Modules & Services



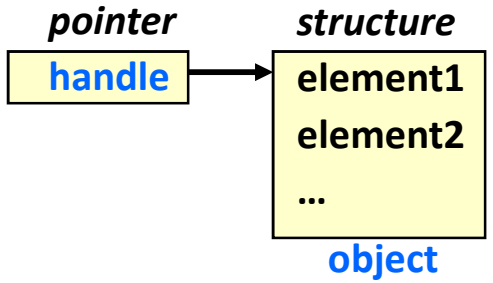
BIOS Configuration

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

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:

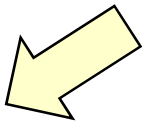
Real-time System

- *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 provides methods for interacting with library routines and data objects*

Comparing RTOS and 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, DSP

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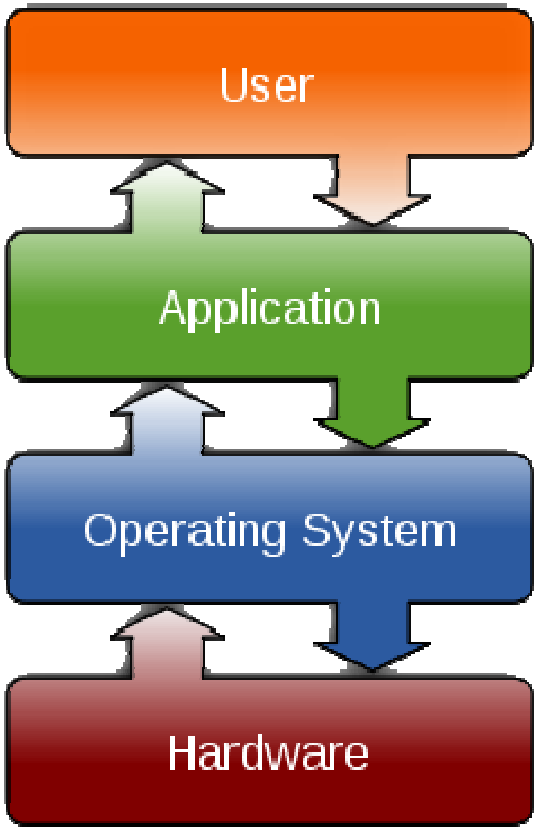
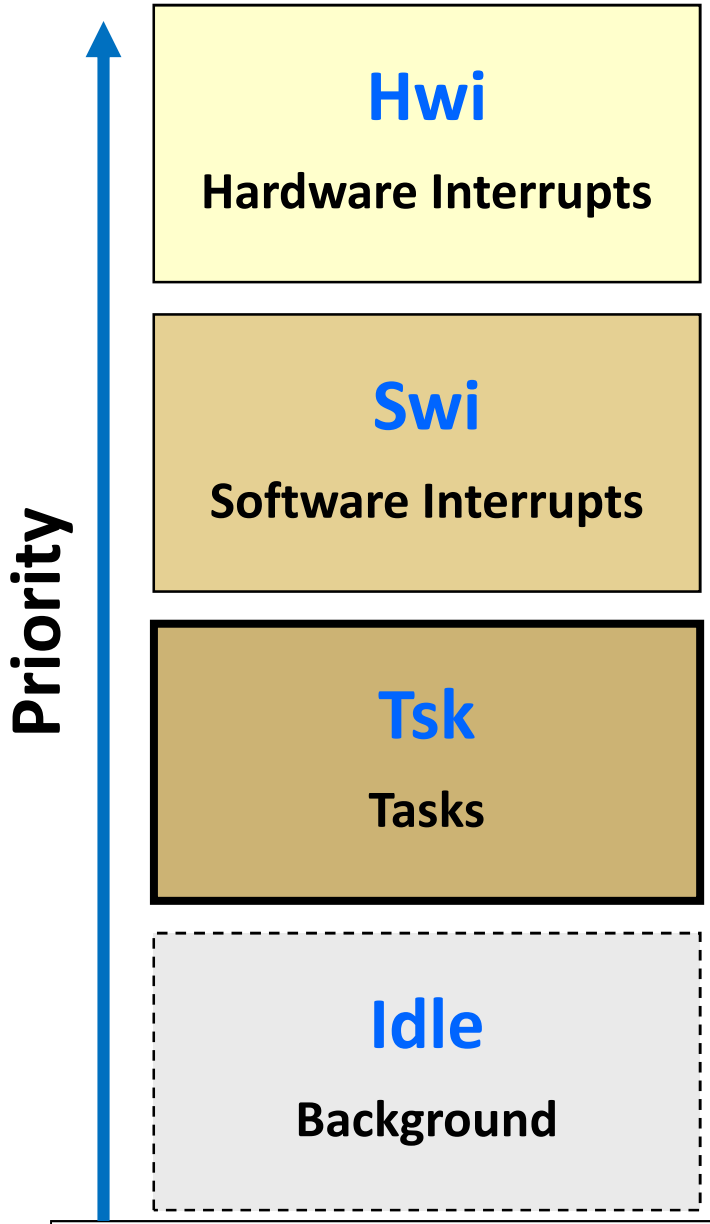


SYS/BIOS Thread Types



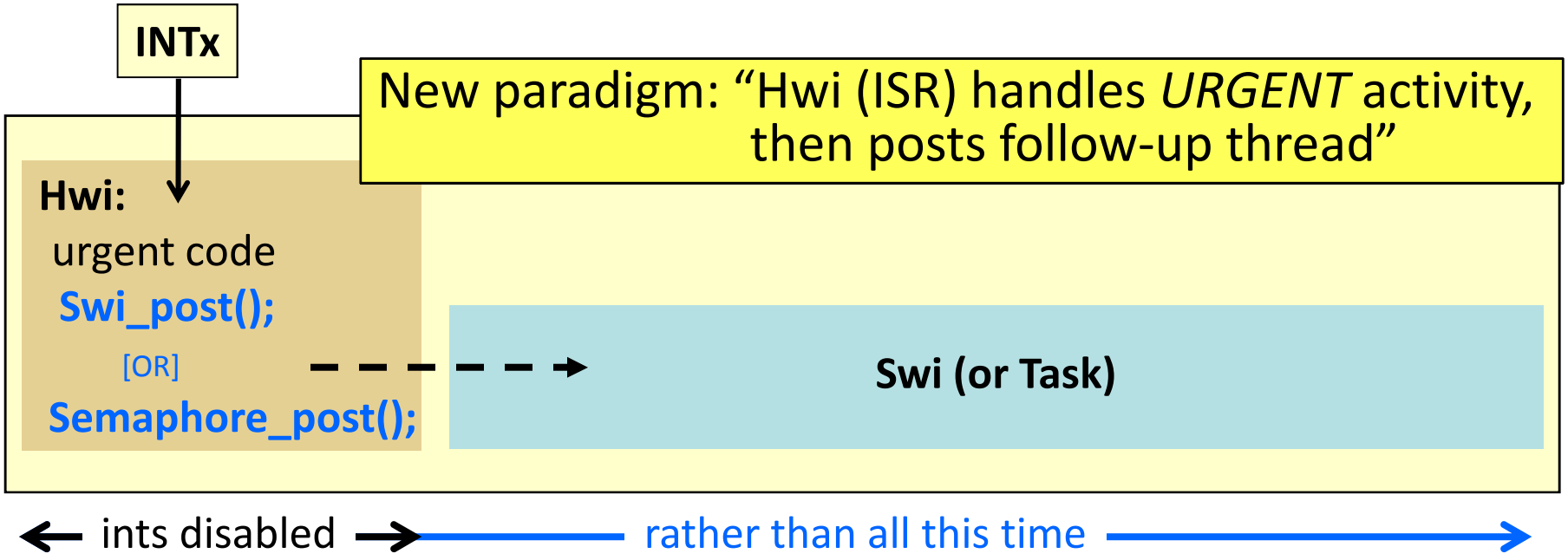
- Implements 'urgent' part of real-time event
- Hardware interrupt triggers ISRs to run
- Priorities set by hardware

- Performs HWI *follow-up* activity
- *Posted* by software
- Periodic (Clock) functions are prioritized as Swi processes
- Up to 32 priority levels

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

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

Hwi Signaling Swi/Task



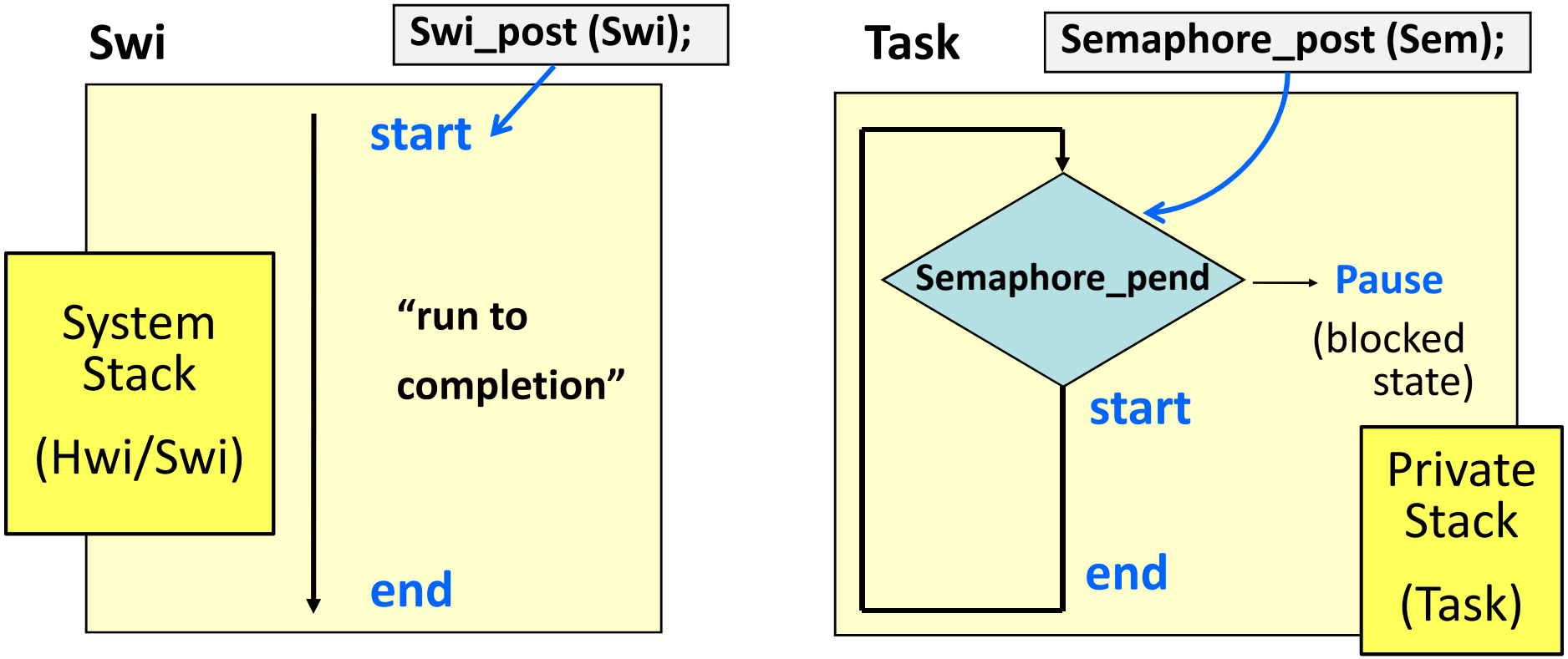
Hwi

- 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 and Tasks



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

- 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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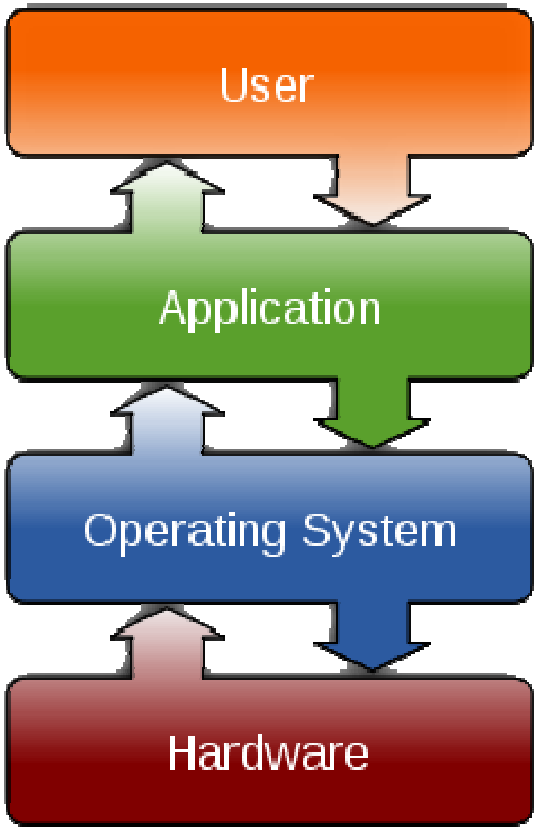


Thread (Object) Creation in BIOS

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

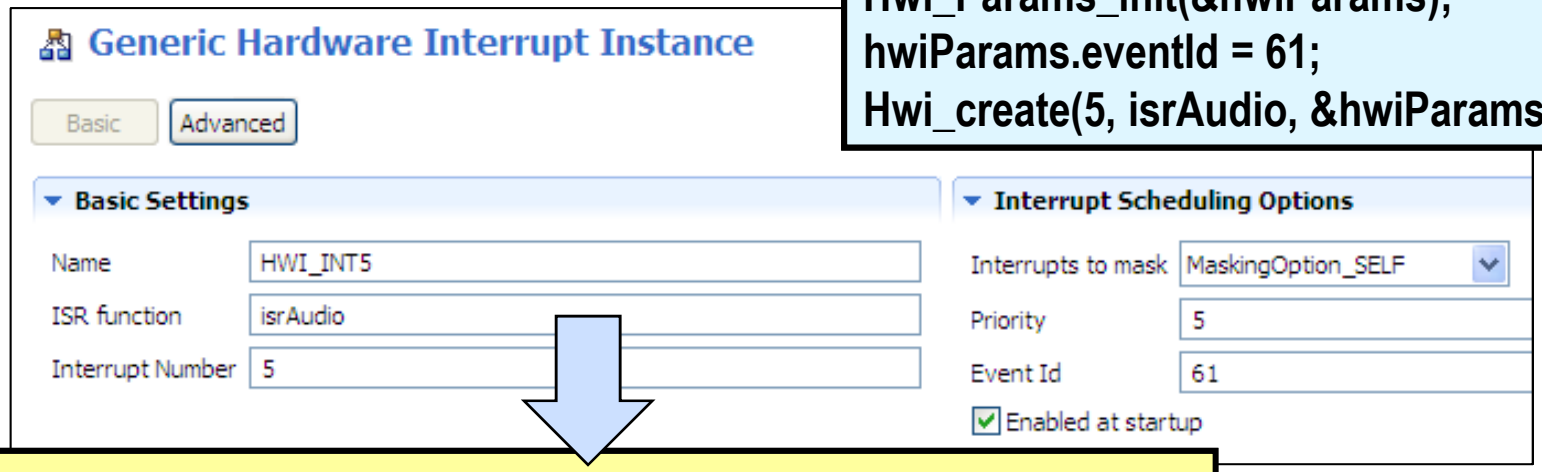
- Statically (via the GUI or .cfg script)
- Dynamically (via C code)
- BIOS doesn't care – but you might…

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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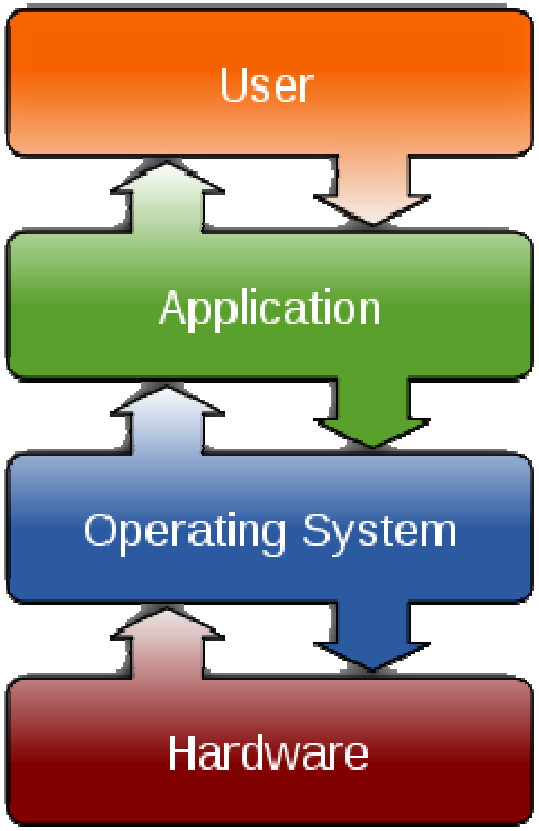
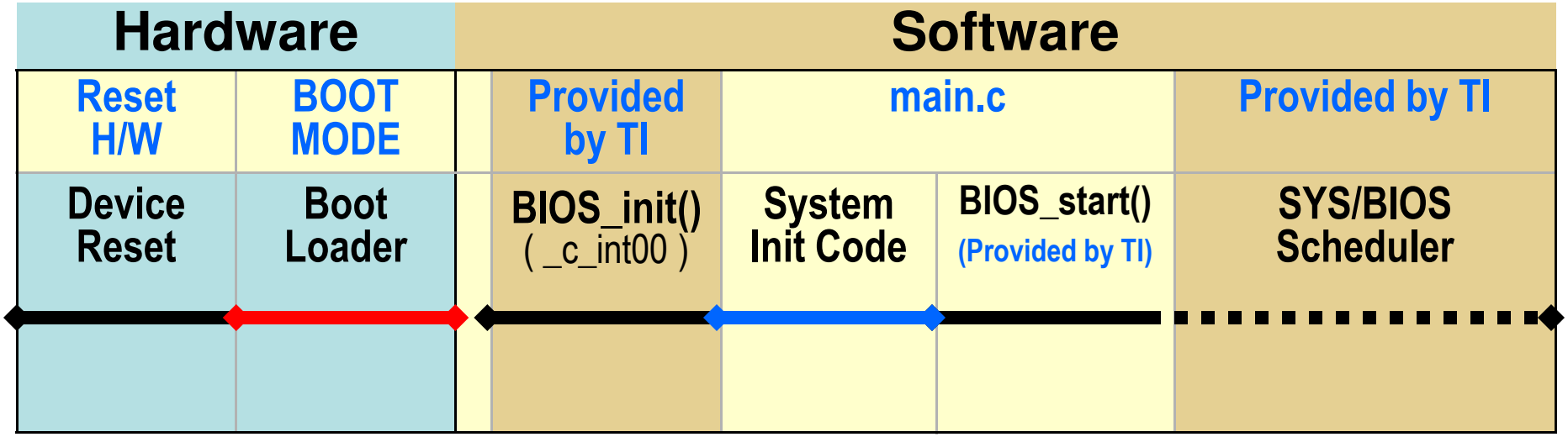


System Timeline



- RESET: Device is reset, then jumps to bootloader or code entry point (`c_int00`)
- BOOT MODE runs bootloader (if applicable)
- `BIOS_init()` configures 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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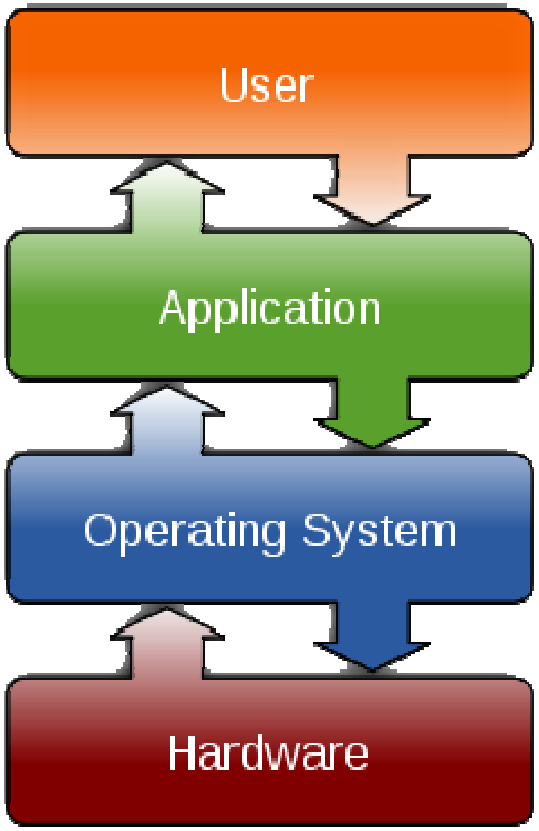
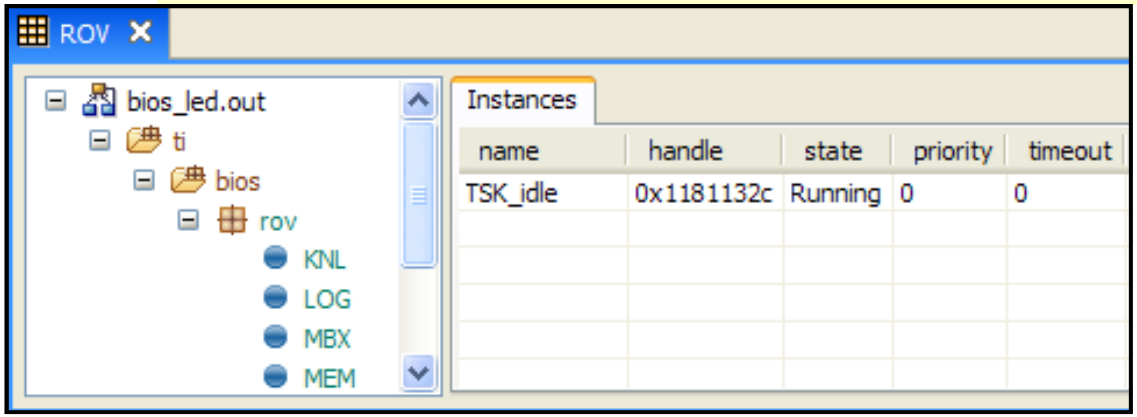


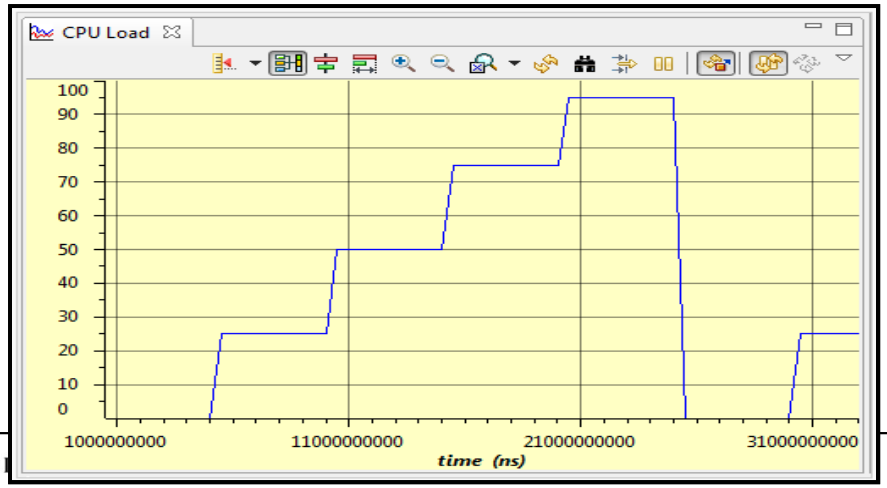
Built-in Real-Time Analysis Tools

- 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()`

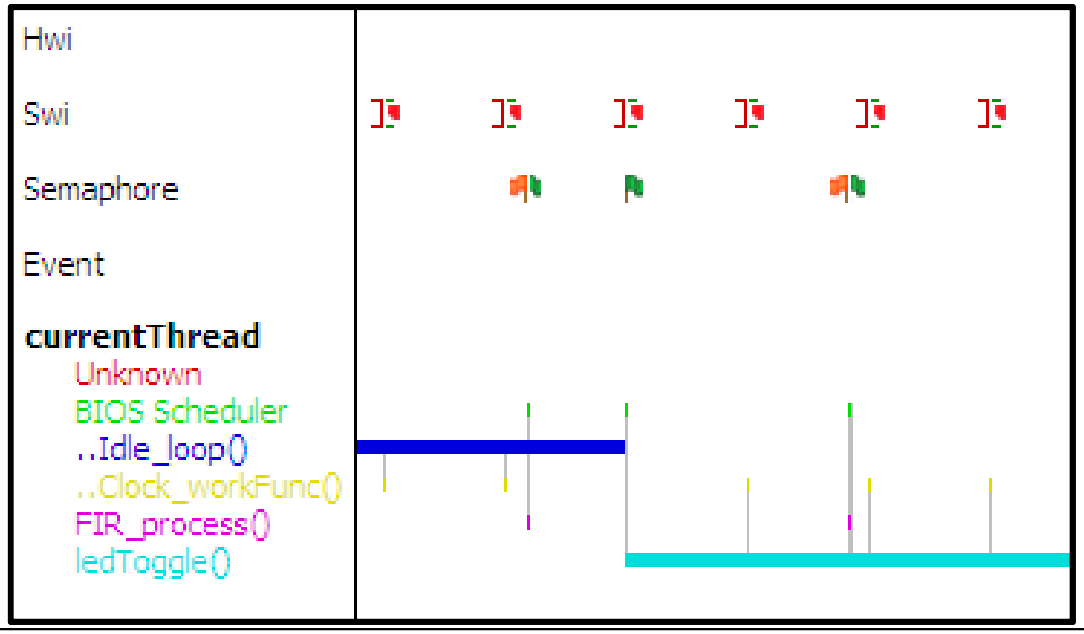
Raw Logs

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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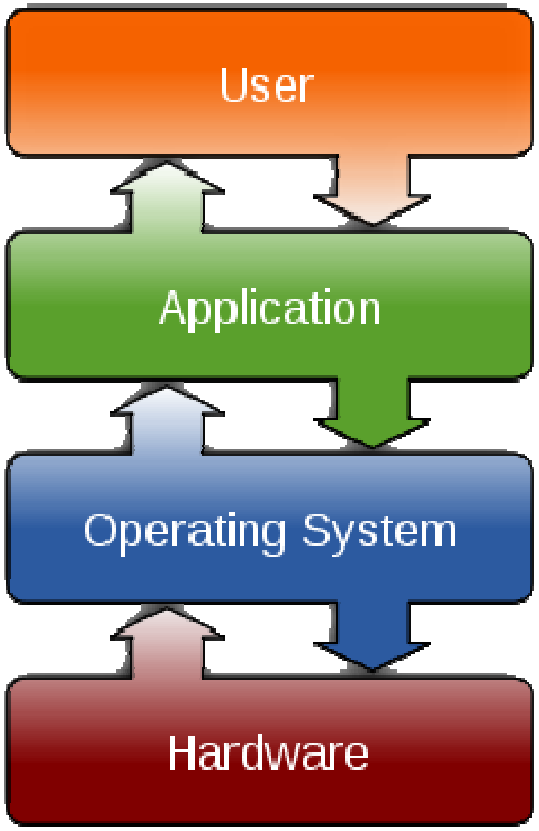
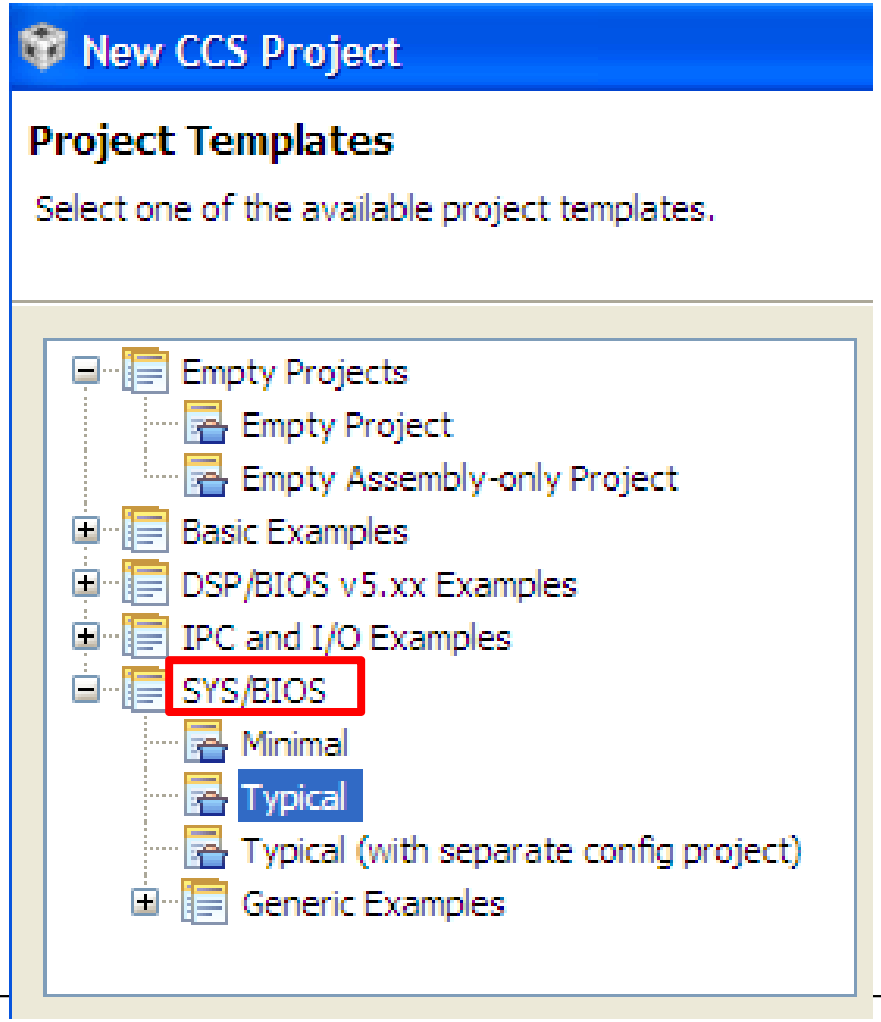


Building a NEW SYS/BIOS Project

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

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

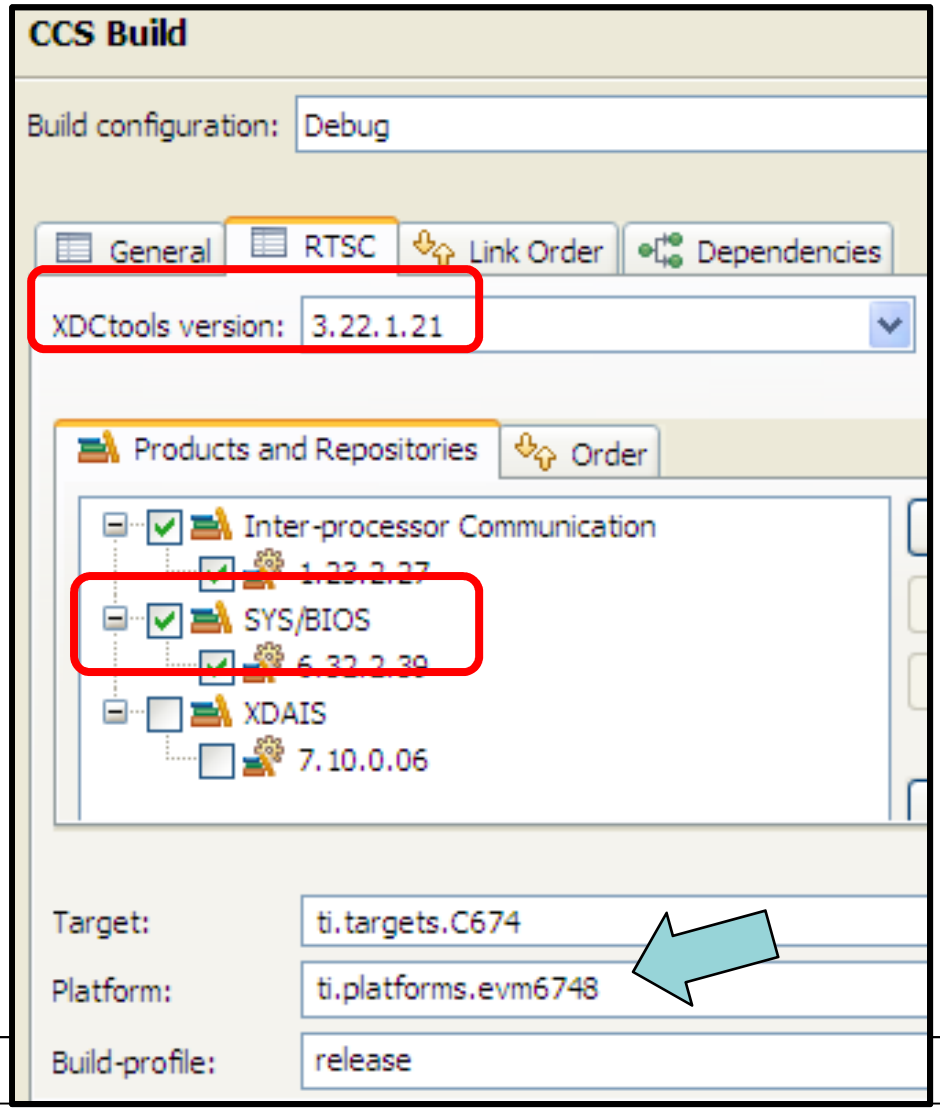


What is in the project created by *Typical*?

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

SYS/BIOS Project Settings

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



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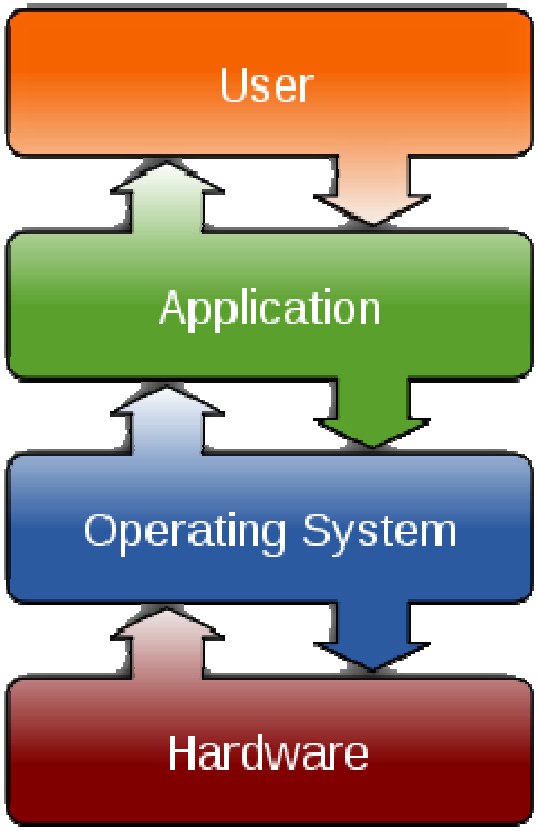
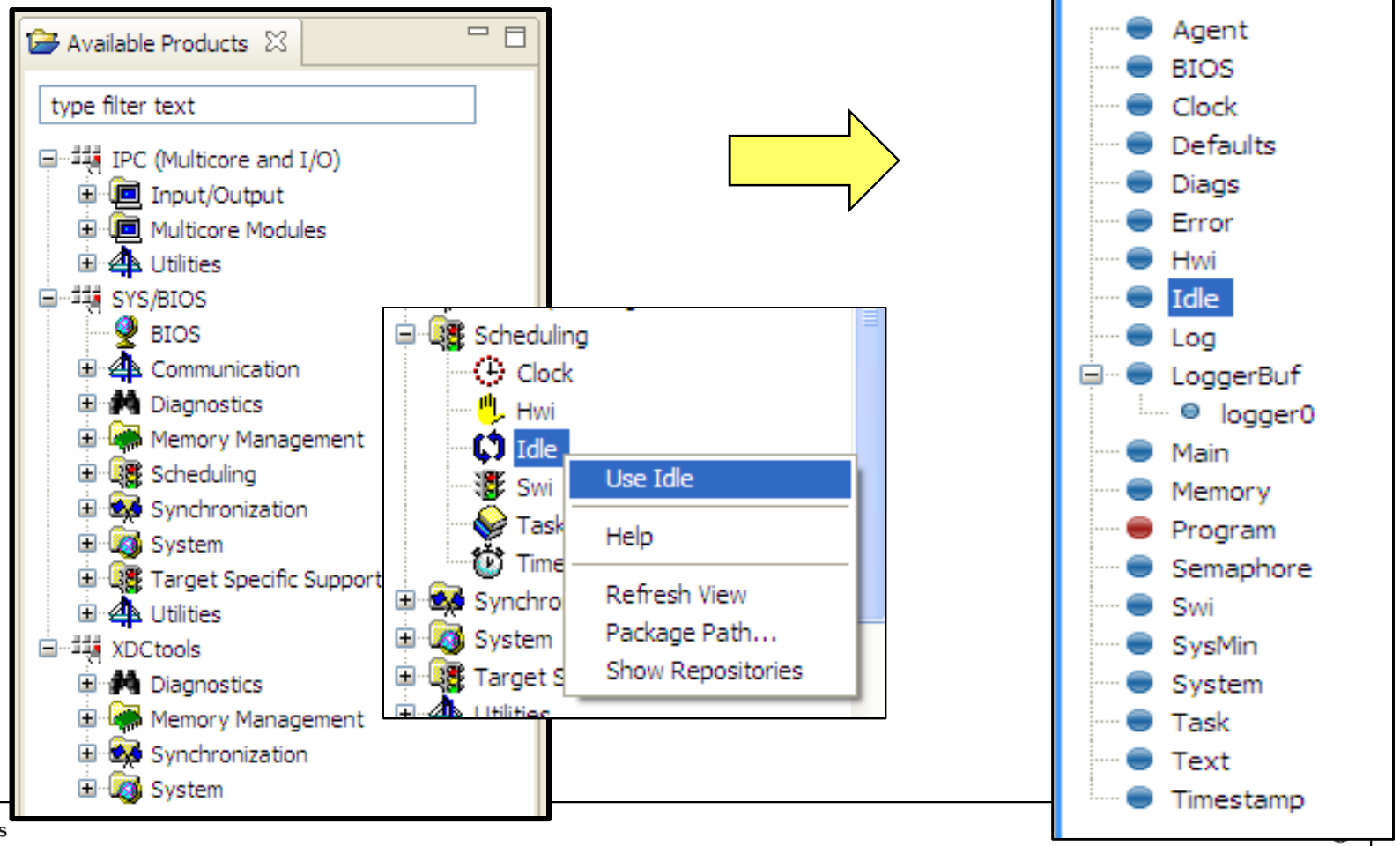


Static BIOS Configuration

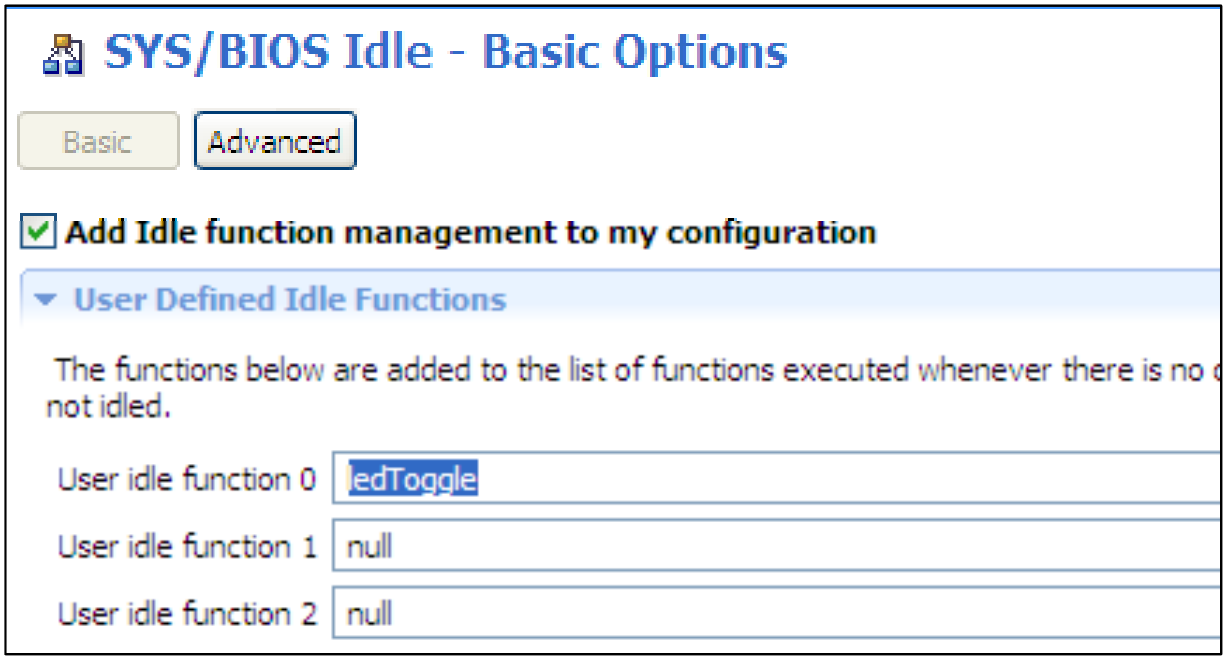
Users interact with the CFG file via the GUI – XGCONF:

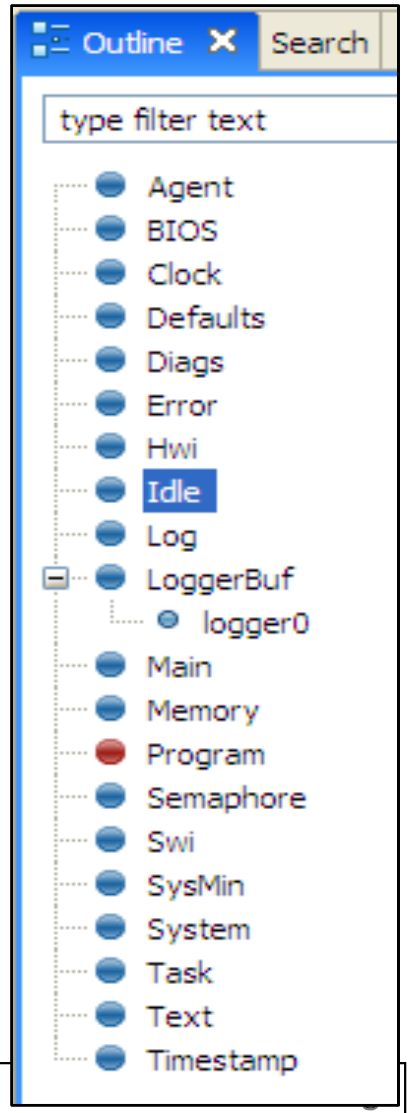
- XGCONF shows *Available Products*; Right-click and select *Use Mod.*
- *Mod* shows up in *Outline* view. Right-click and select *Add New.*
- All graphical changes in GUI are displayed in .cfg source code.



Static Config – .CFG Files

- **Users interact with the CFG file via the GUI – XGCONF**
  - When you *Add New*, a dialogue box is provided to set up parameters.
  - This window provides two views:
    - *Basic*
    - *Advanced*





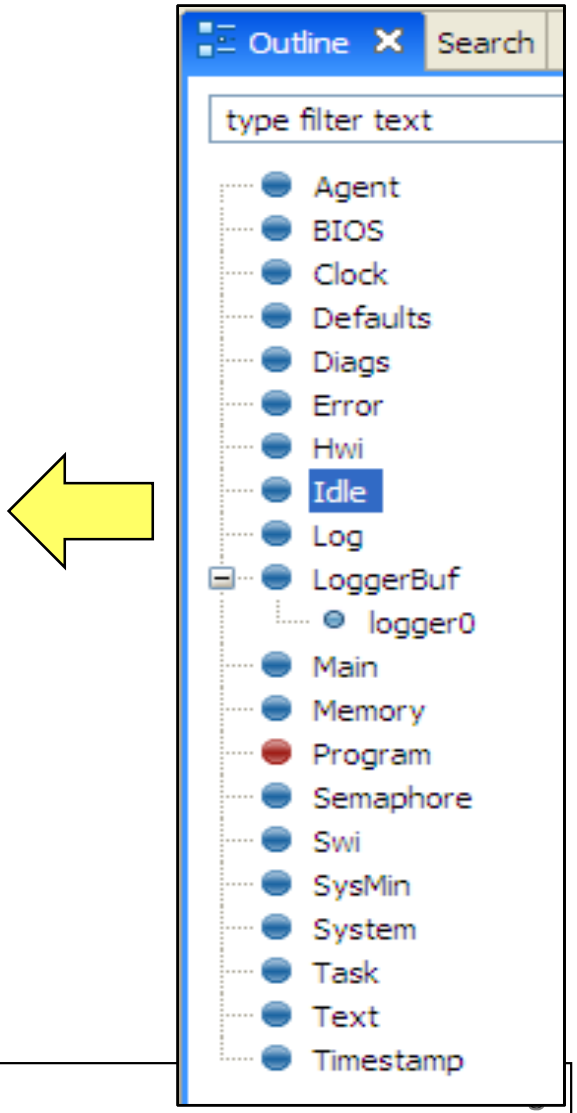
.CFG Files (XDC script)

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

app.cfg

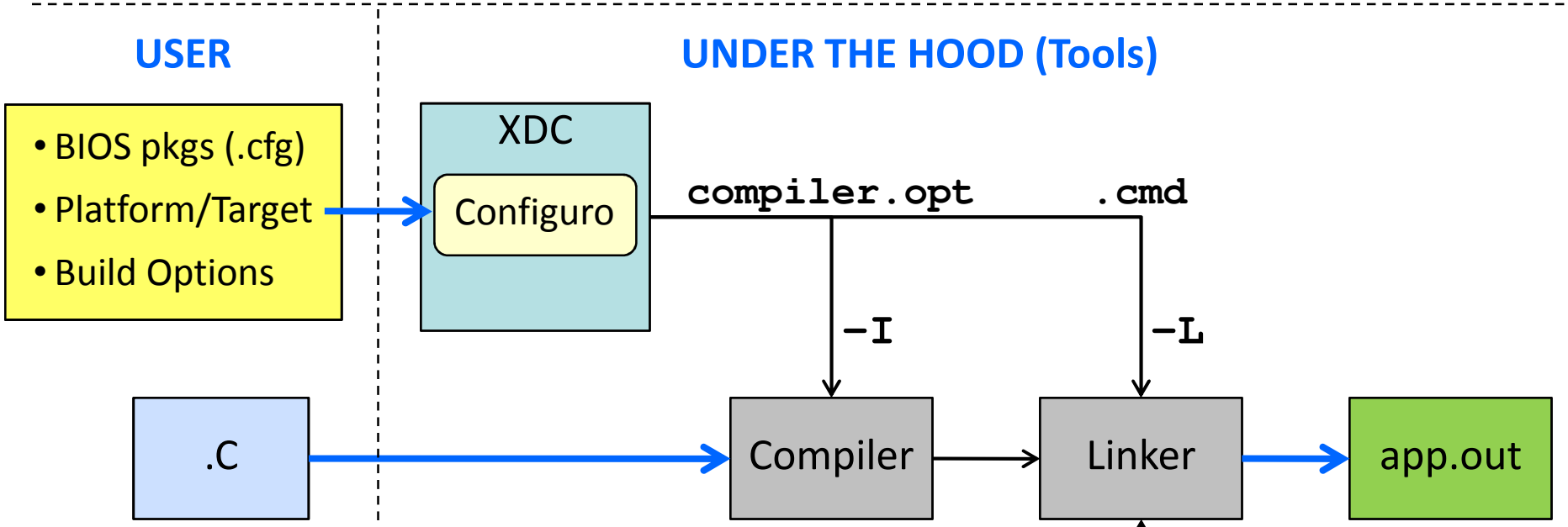
```
11
12var BIOS = xdc.useModule('ti.sysbios.BIOS');
13var Clock = xdc.useModule('ti.sysbios.knl.Clock');
14var Swi = xdc.useModule('ti.sysbios.knl.Swi');
15var Task = xdc.useModule('ti.sysbios.knl.Task');
16var Semaphore = xdc.useModule('ti.sysbios.knl.Semaphore');
17var Hwi = xdc.useModule('ti.sysbios.hal.Hwi');
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 (e.g., Hwi, Clock, Semaphore, etc.) are delivered as RTSC compliant packages.
- RTSC (Real Time Software Components) are packages that contain libraries and metadata (similar to Java.jar files)
- XDC (eXpress DSP Components) is a set of tools that consume RTSC packages (knows how to read RTSC metadata).

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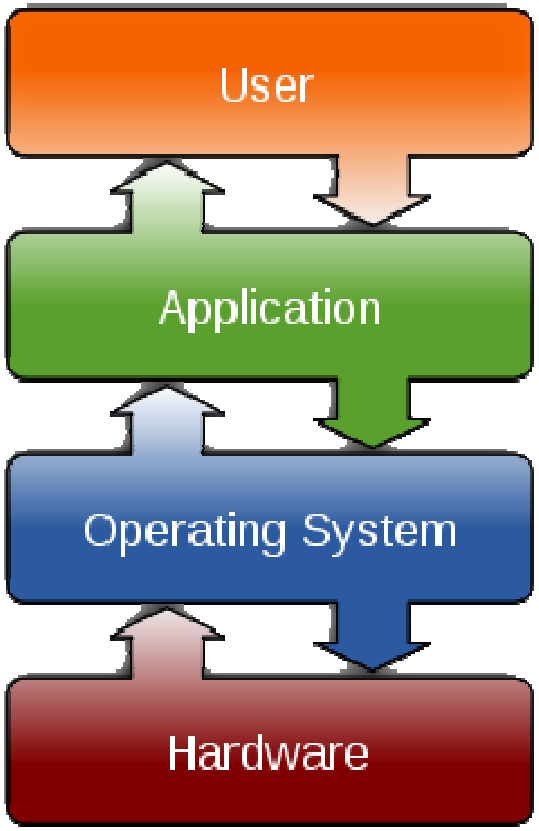


Platform (Memory Config)

Memory Configuration

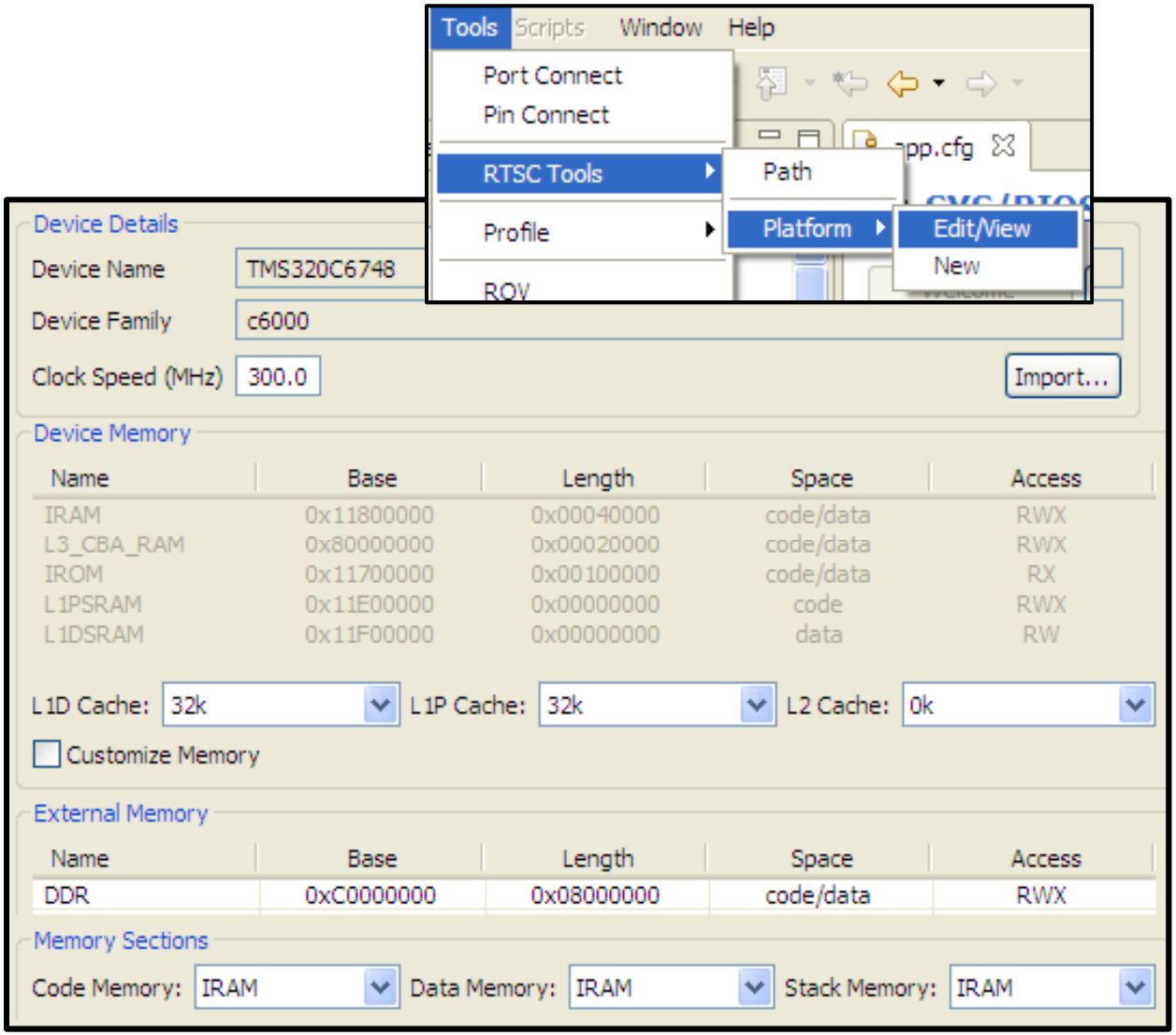
- Create Internal Memory Segments (e.g. IRAM)
- Configure cache
- Define External Memory Segments

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



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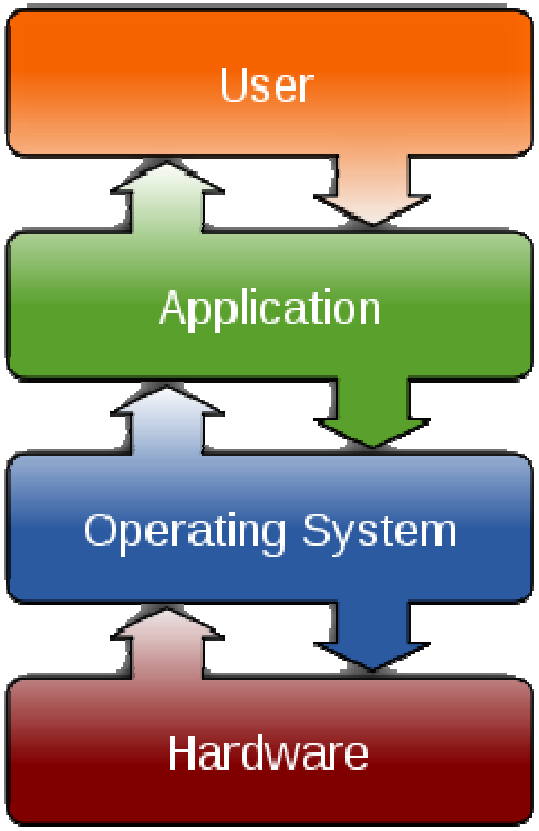
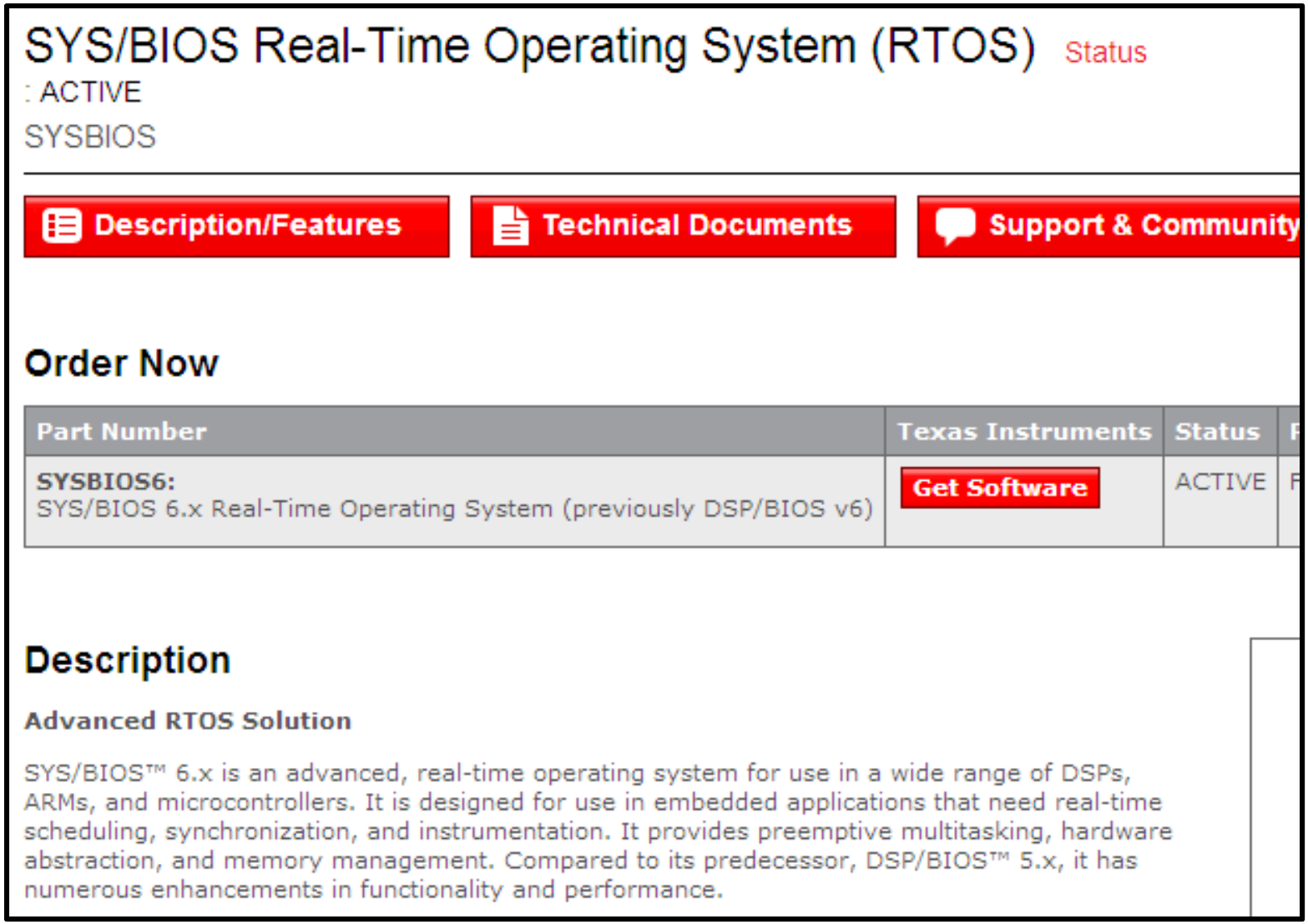


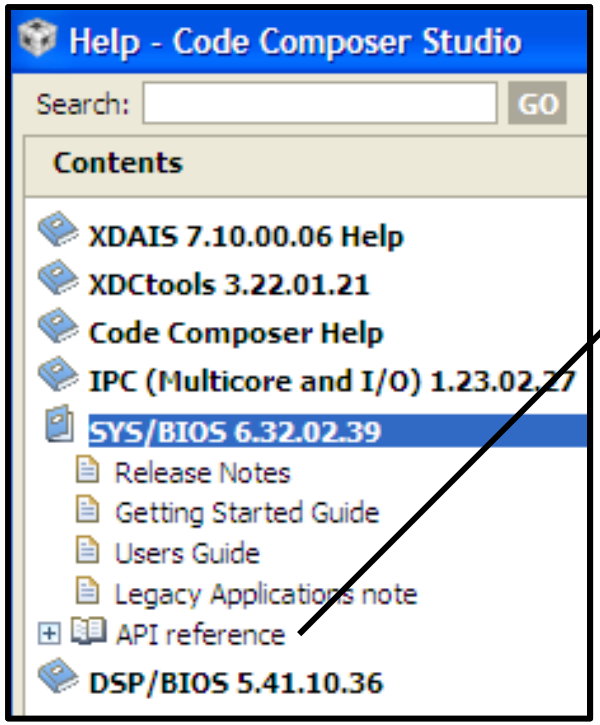
For More Information (1)

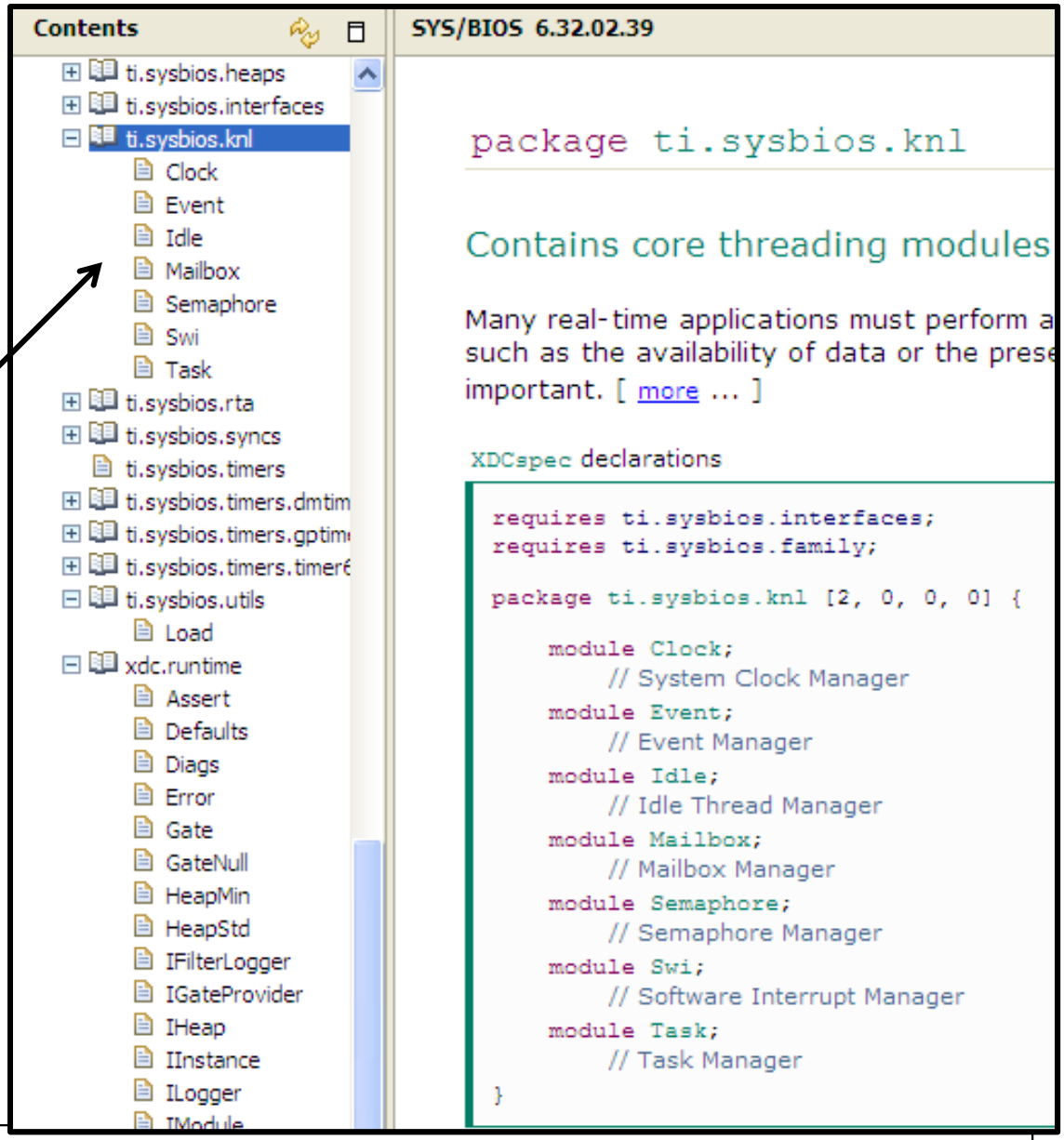
- **SYS/BIOS Product Page http://www.ti.com/sysbios**



For More Information (2)

- **CCS Help Contents**



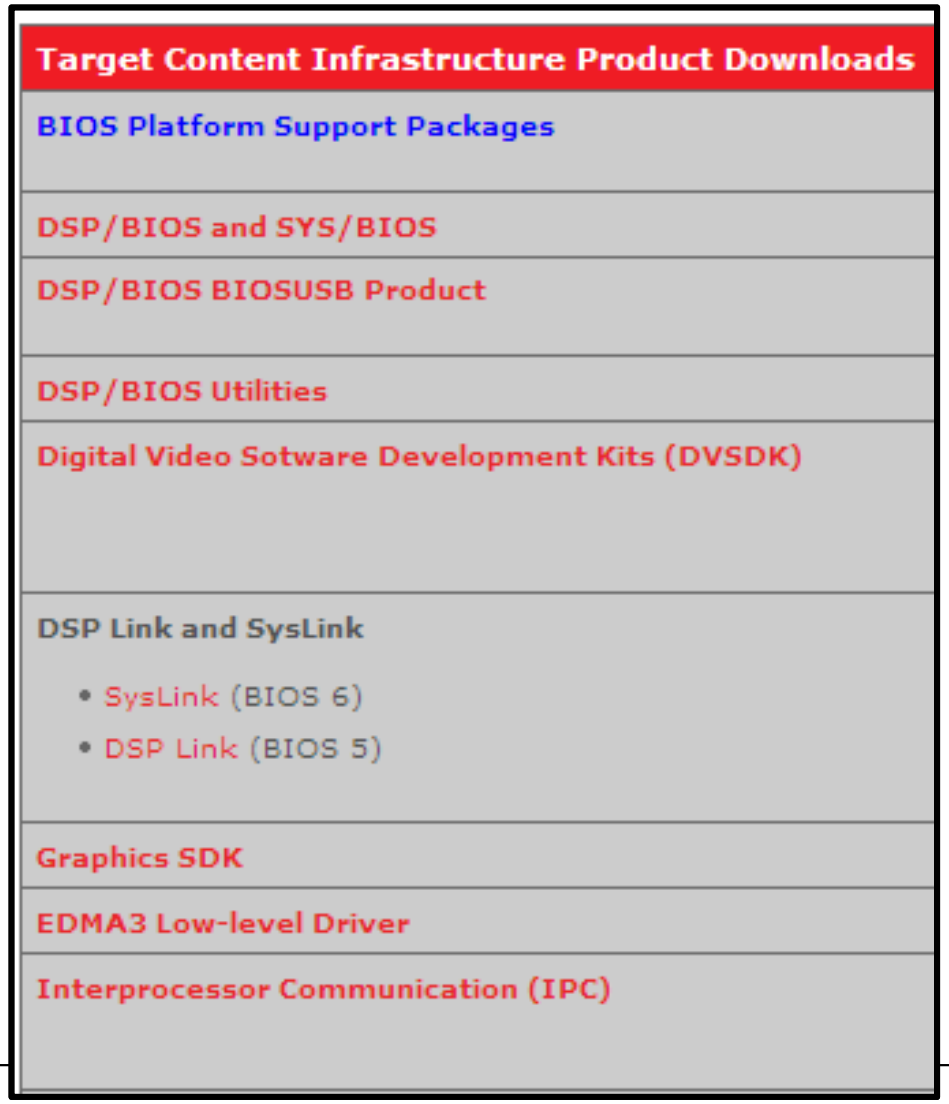


- User Guides
- API Reference (knl)

Download Latest Tools

- **Download Target Content**

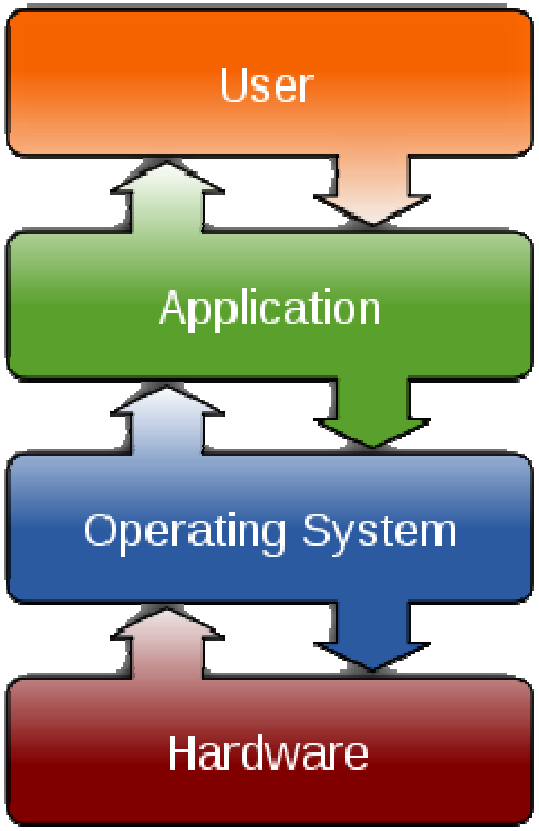
http://software-dl.ti.com/dsps/dsps_public_sw/sdo_sb/targetcontent/



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

Outline

- Intro to SYS/BIOS
- BIOS Threads
  - Hardware Interrupts (Hwi)
  - Software Interrupts (Swi)
  - Tasks (Tsk)
  - Semaphores (Sem)



Hwi Scheduling

Hard R/T

Hwi
Hardware Interrupts

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

Swi
Software Interrupts

- Up to 32 priority levels
- Any number possible, all preemptive

Tsk
Tasks

- Up to 32 priority levels
- Any number possible, all preemptive

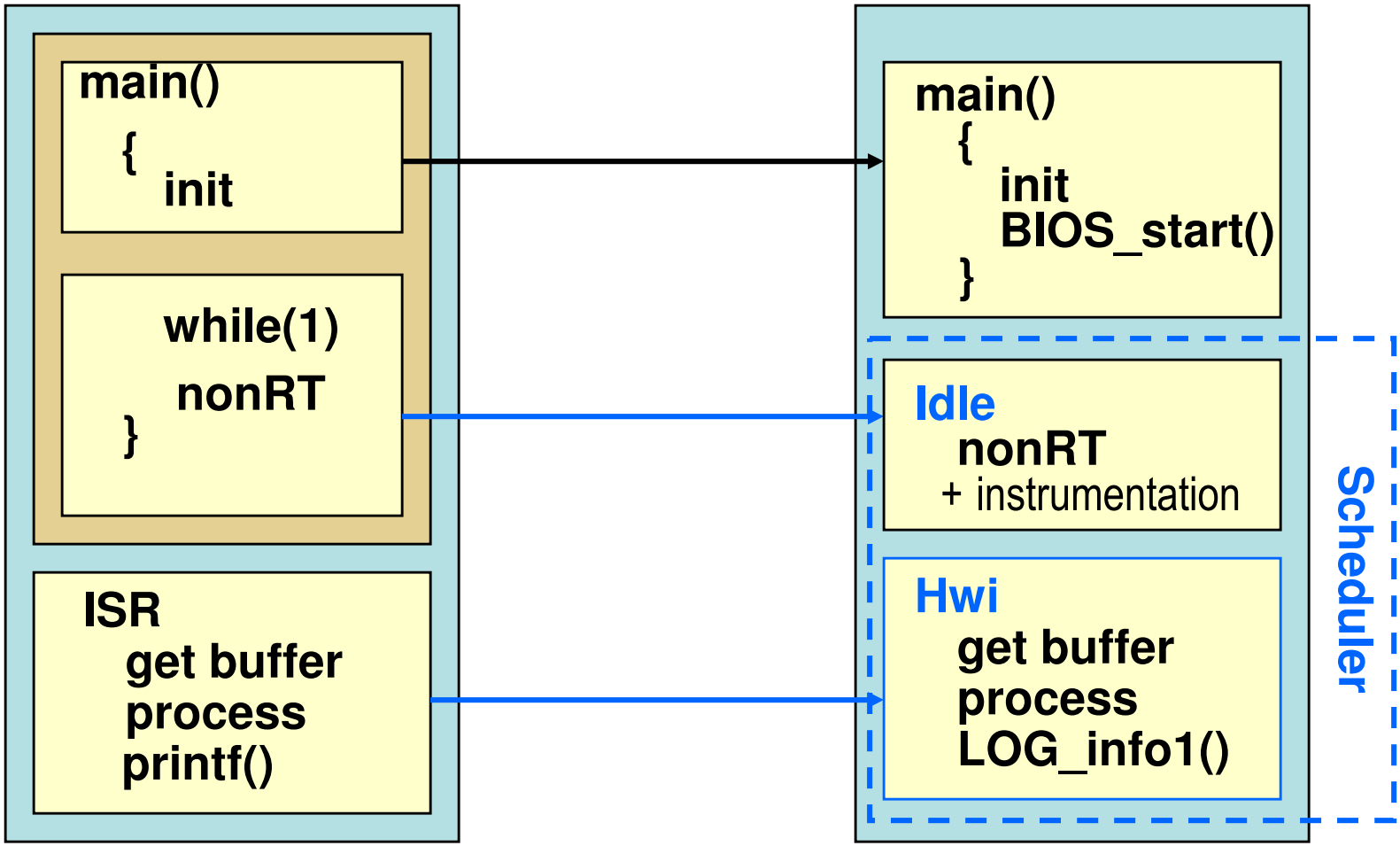
Soft R/T

Idle
Background

- Continuous loop
- Non-realtime in nature

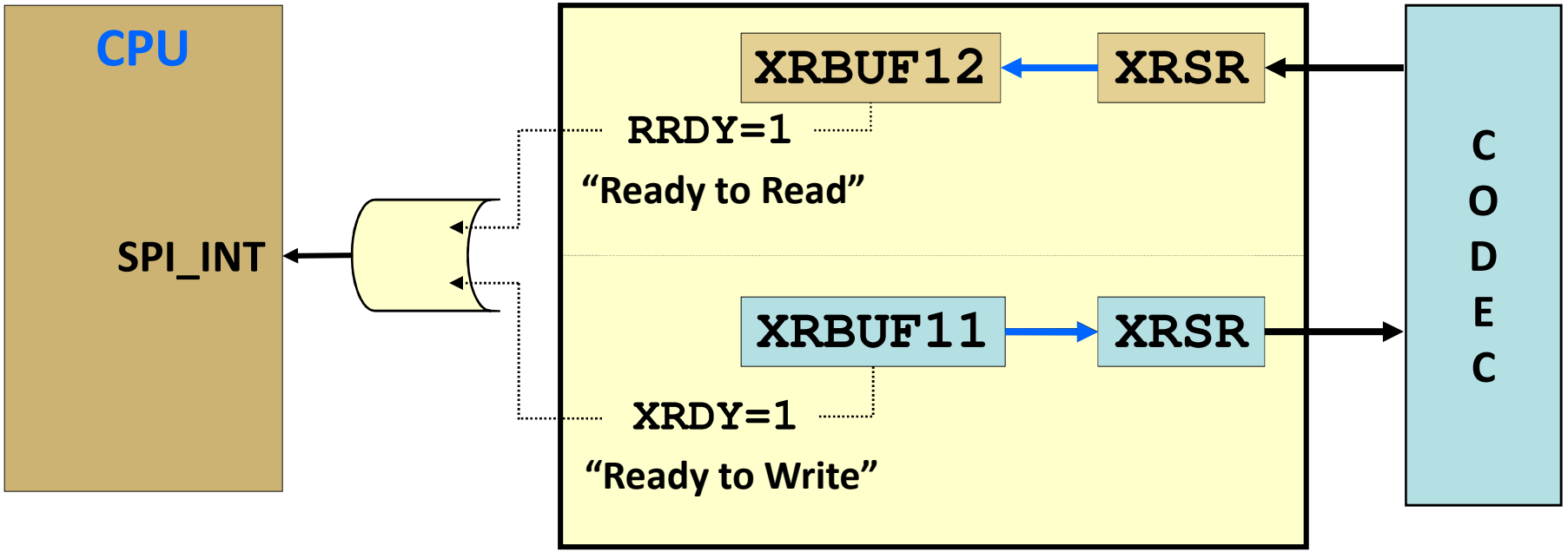
- Idle events run in sequence when no Hwi are posted.
- Hwi is ISR with automatic vector table generation + context save/restore.
- Any Hwi preempts Idle, Hwi may preempt other Hwi if desired.

Foreground / Background Scheduling



- Idle events run in sequence when no Hwi 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 (SPI)



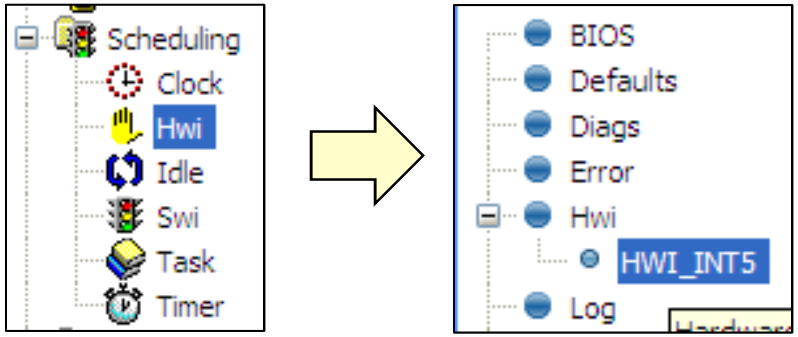
- A peripheral (e.g., SPI on C6678) causes an interrupt to the CPU to indicate "service required."
- This "event" will have an ID (datasheet) and can be tied to a specific CPU interrupt (target specific).

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

Configuring an Hwi: Statically via GUI

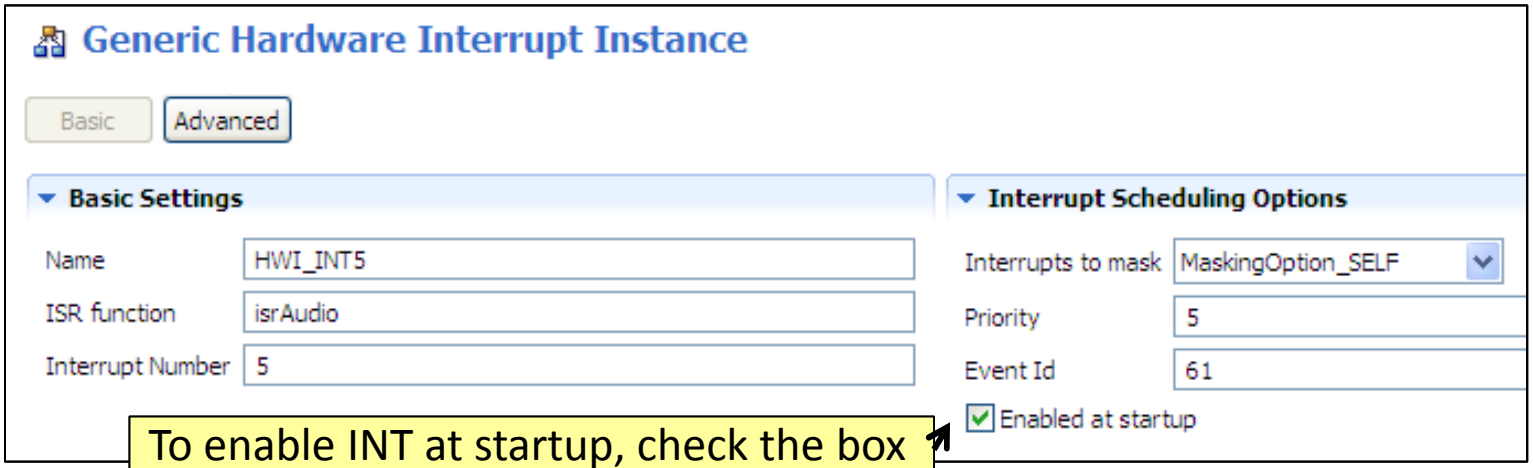
Example: Tie SPI_INT to the CPU HWI_5

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



NOTE: 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 #?

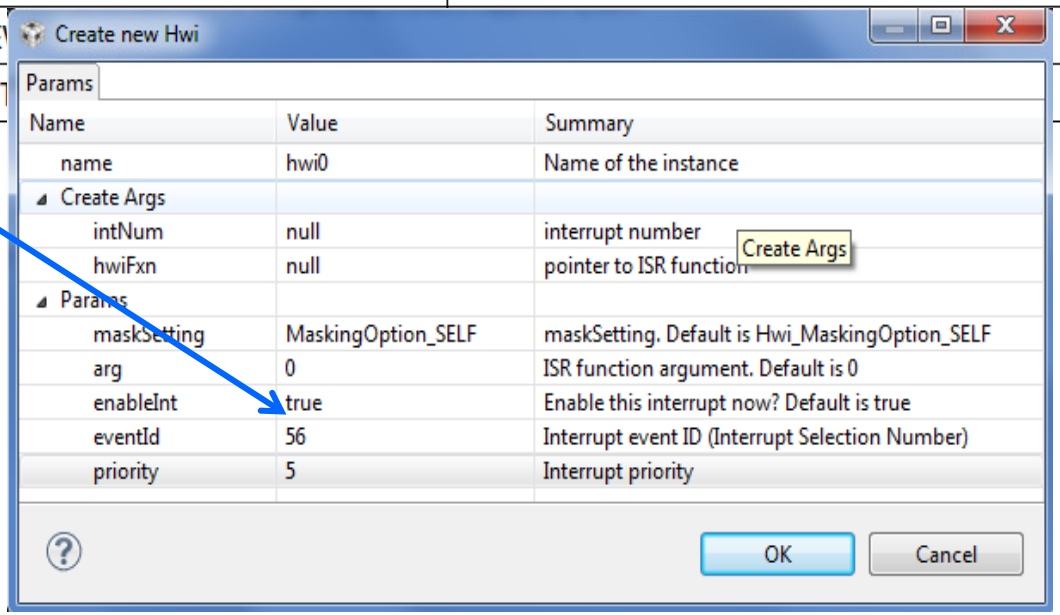
Hardware Event IDs

- How do you know the names of the interrupt events and their corresponding event numbers?

  Look it up in the datasheet.

Source: TMS320C6678 datasheet

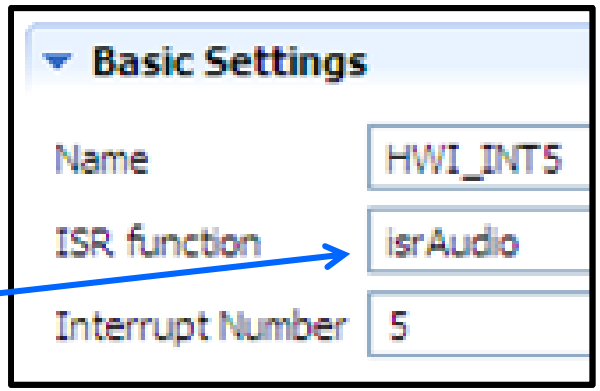
52	PCIEXpress_Legacy_INTC	Legacy interrupt mode
53	PCIEXpress_Legacy_INTD	Legacy interrupt mode
54	SPIINT0	SPI interrupt0
55	SPIINT1	SPI interrupt1
56	SPIXEVT	Transmit event
57	SPIRE	
58	I2CINT	



- As appropriate, refer to the datasheet for your target platform.

Example ISR (SPI)

Example ISR for SPIXEVT_INT interrupt



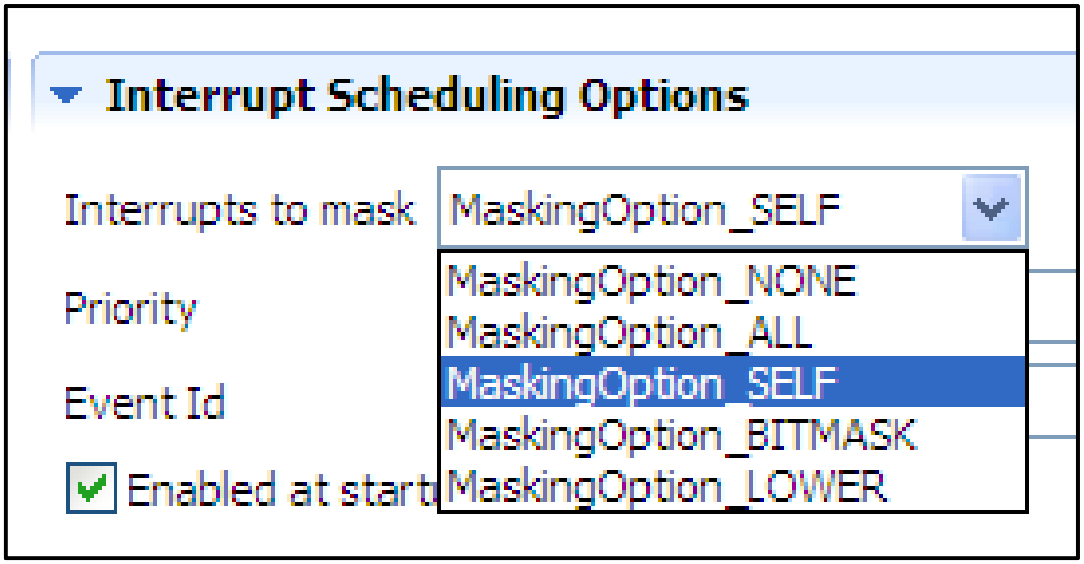
isrAudio:

```
pInBuf[blkCnt] = SPI->RCV;        // READ audio sample from SPI
SPI->XMT = pOutBuf[blkCnt]        // WRITE audio sample to SPI
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 activities 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()`	Set enable bit = 0
`Hwi_enableInterrupt()`	Set enable bit = 1
`Hwi_clearInterrupt()`	Clear INT flag bit = 0
`Hwi_post()` **New in SYS/BIOS**	Post INT # (in code)
`Hwi_disable()`	Global INTs disable
`Hwi_enable()`	Global INTs enable
`Hwi_restore()`	Global INTs restore

Outline

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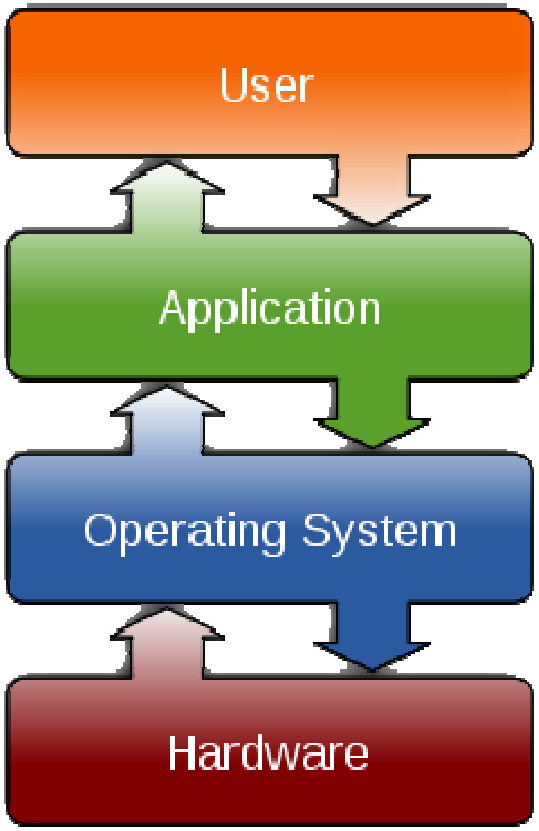
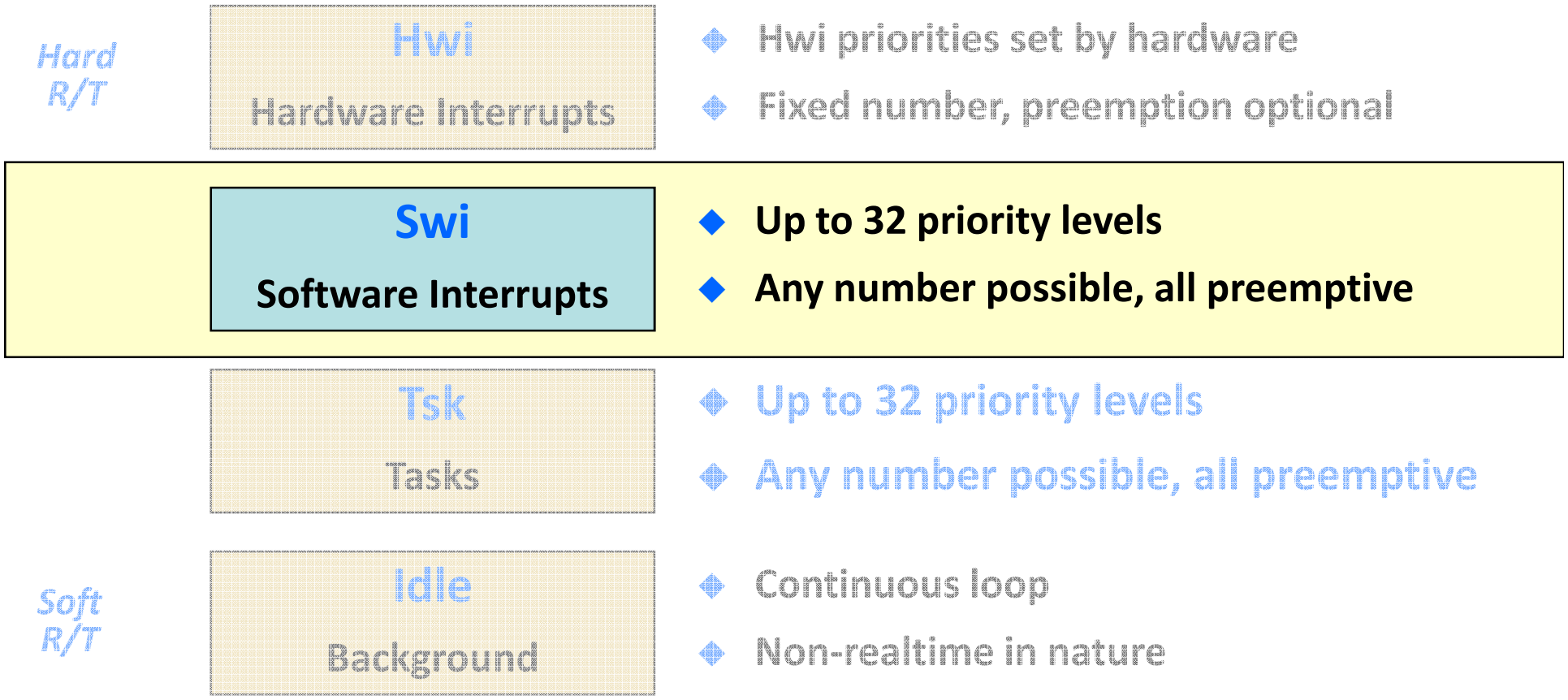
  - **Software Interrupts (Swi)**
  - Tasks (Tsk)
  - Semaphores (Sem)



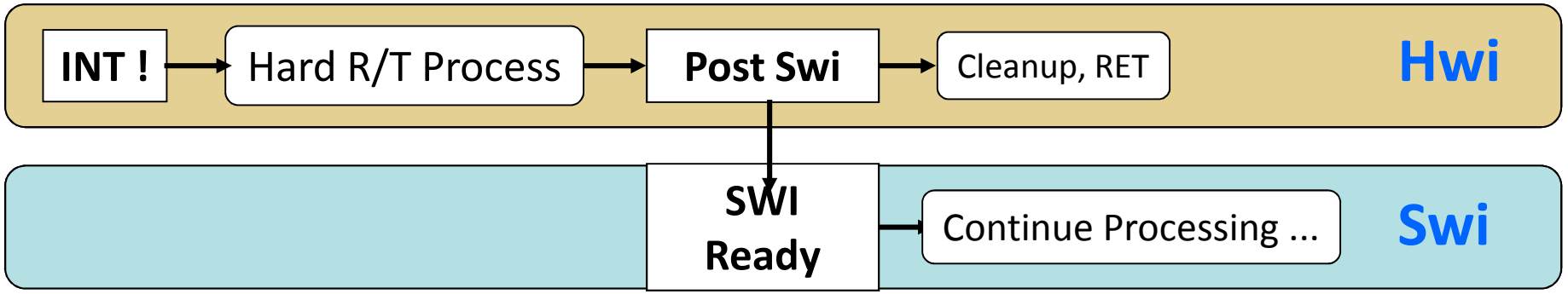
Swi Scheduling



- 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:

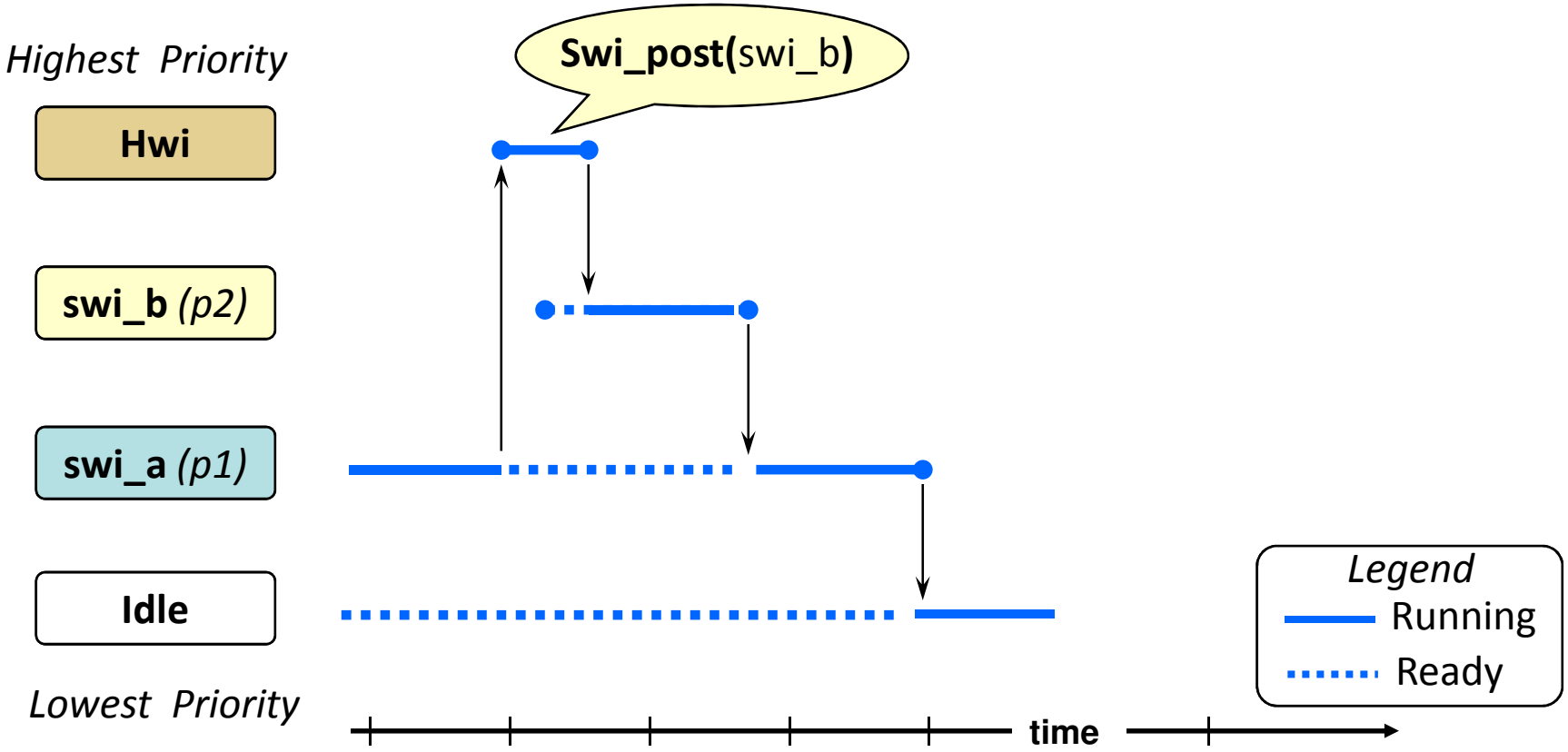
```
*buf++ = *XBUF;
cnt++;
if (cnt >= BLKSZ) {
   Swi_post(swiFir);
   count = 0;
   pingPong ^= 1;
}
```

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.

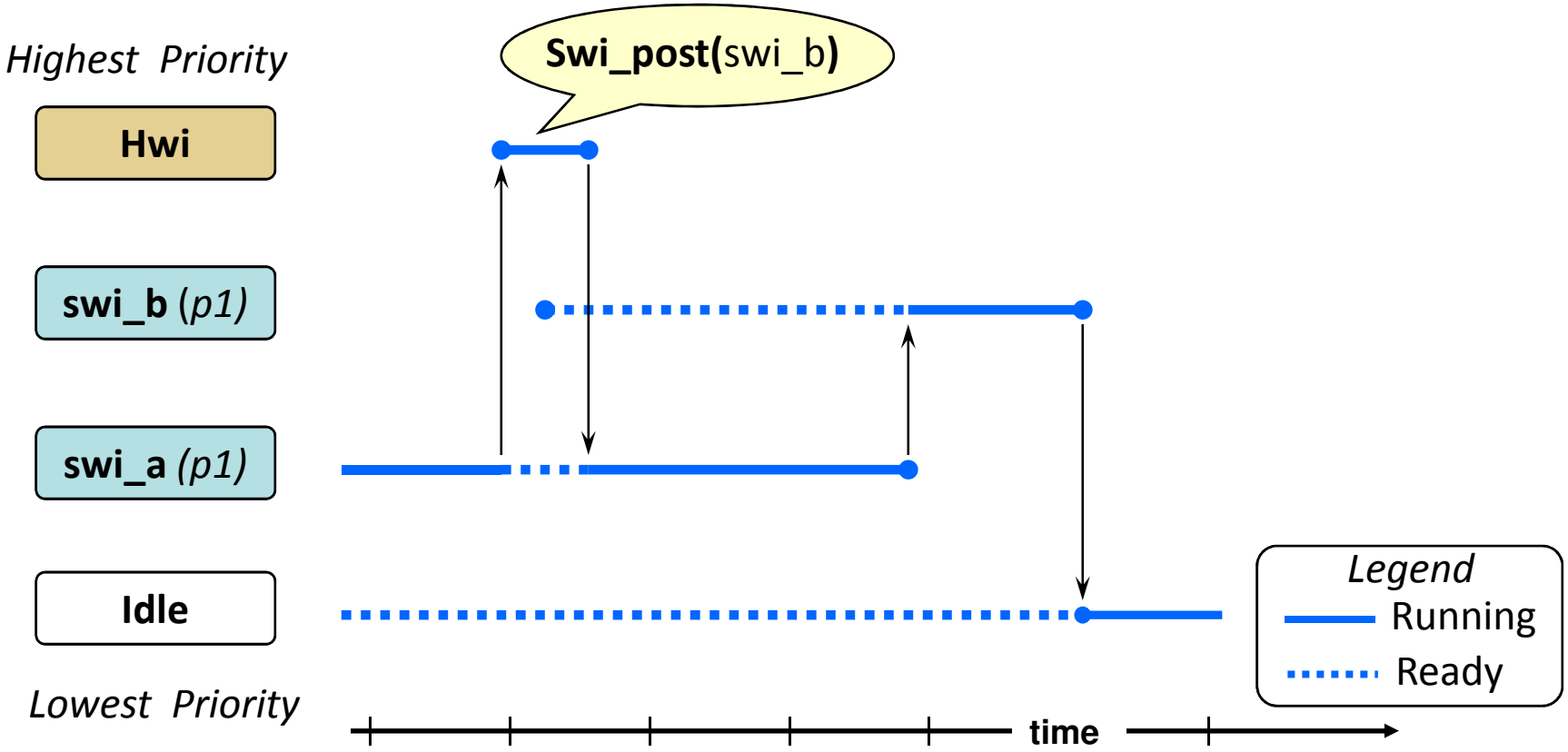
Scheduling Rules



- ***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 range from 1 to 32.
- Automatic context switch (uses system stack)

What if more than one Swi process is set to the same priority?

Scheduling Rules

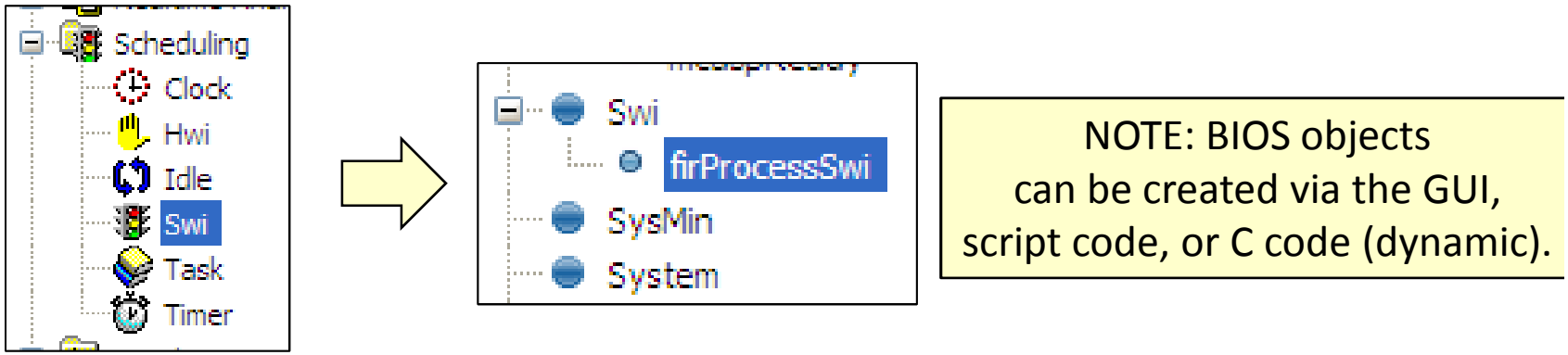


- Processes of same priority are scheduled first-in first-out (FIFO).
- Having threads at the SAME priority offers certain advantages, such as resource sharing (without conflicts).

Configuring a Swi: Statically via GUI

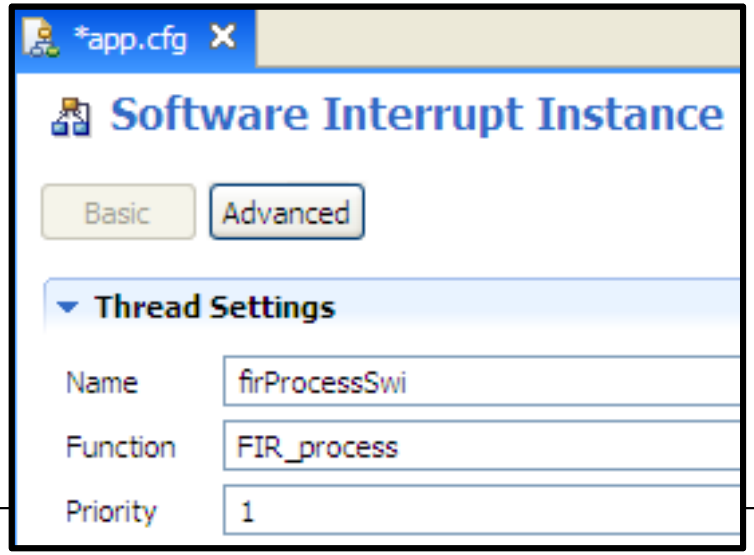
Example: **Tie isrAudio() fxn to Swi; Use priority 1**

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



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

2 **Configure Swi – Object name, function, priority:**



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

Outline

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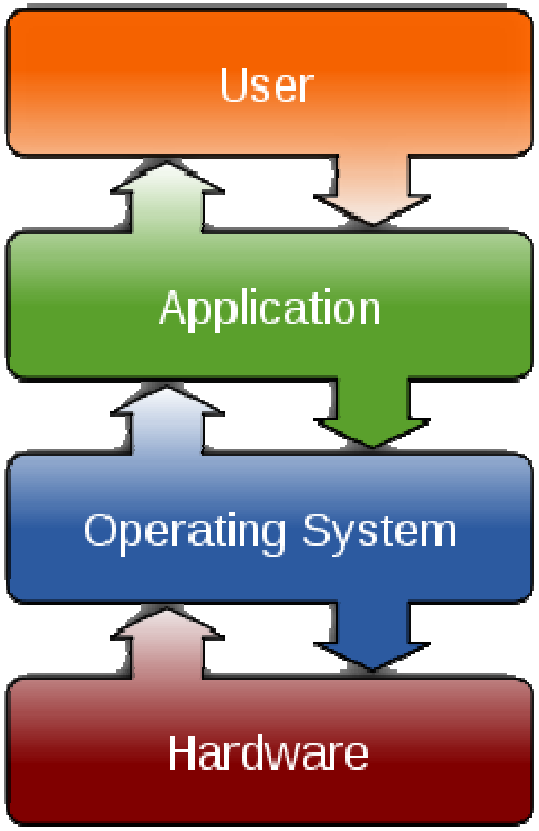


Task Scheduling

Hard R/T

Hwi
Hardware Interrupts

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

Swi
Software Interrupts

- Up to 32 priority levels
- Any number possible, all preemptive

Tsk
Tasks

- **Up to 32 priority levels**
- **Any number possible, all preemptive**

Soft R/T

Idle
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 Tsk, 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.

How is a Task is different from a Swi?.

Comparing Swi and 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** share system stack w/ Hwi
- Usage: As follow-up to Hwi and/or when memory size is an absolute premium

Task

_create →

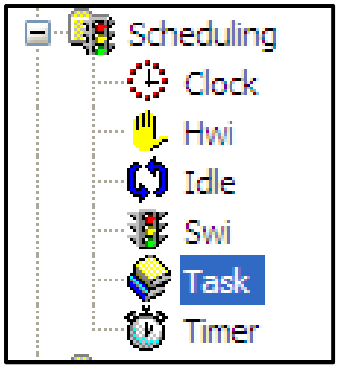
```
void myTask () {
   // Prologue (set Task env)
   while(cond){
      Semaphore_pend();
      *** RUN ***
   }
   // Epilogue (free env)
}
```

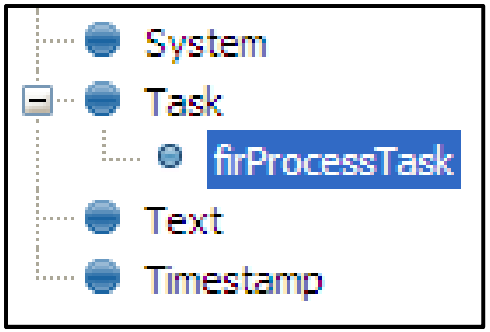
- "Ready" when *CREATED* (BIOS_start or dynamic)
- P-L-E structure handy for resource creation (P) and deletion (E), initial state preserved
- Can block/suspend on semaphore (flag)
- Context switch speed (~160c)
- Uses its OWN stack to store context
- Usage: Full-featured sys, CPU w/more speed/mem

Configuring a Task: Statically via the GUI

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

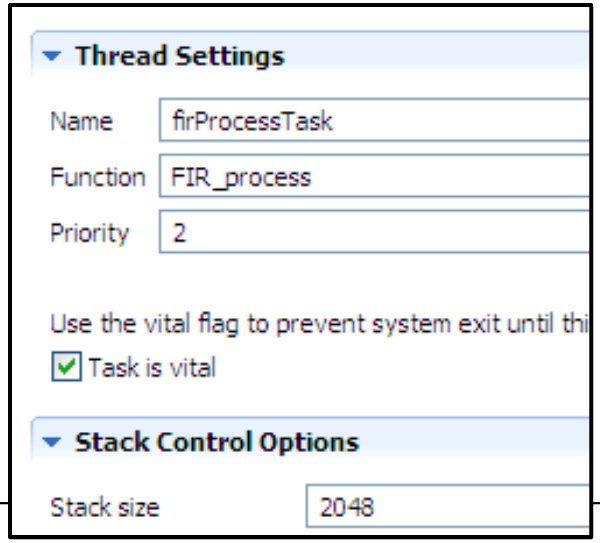
1 **Use Task module** *(Available Products)* **, insert new Task** *(Outline View)*





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

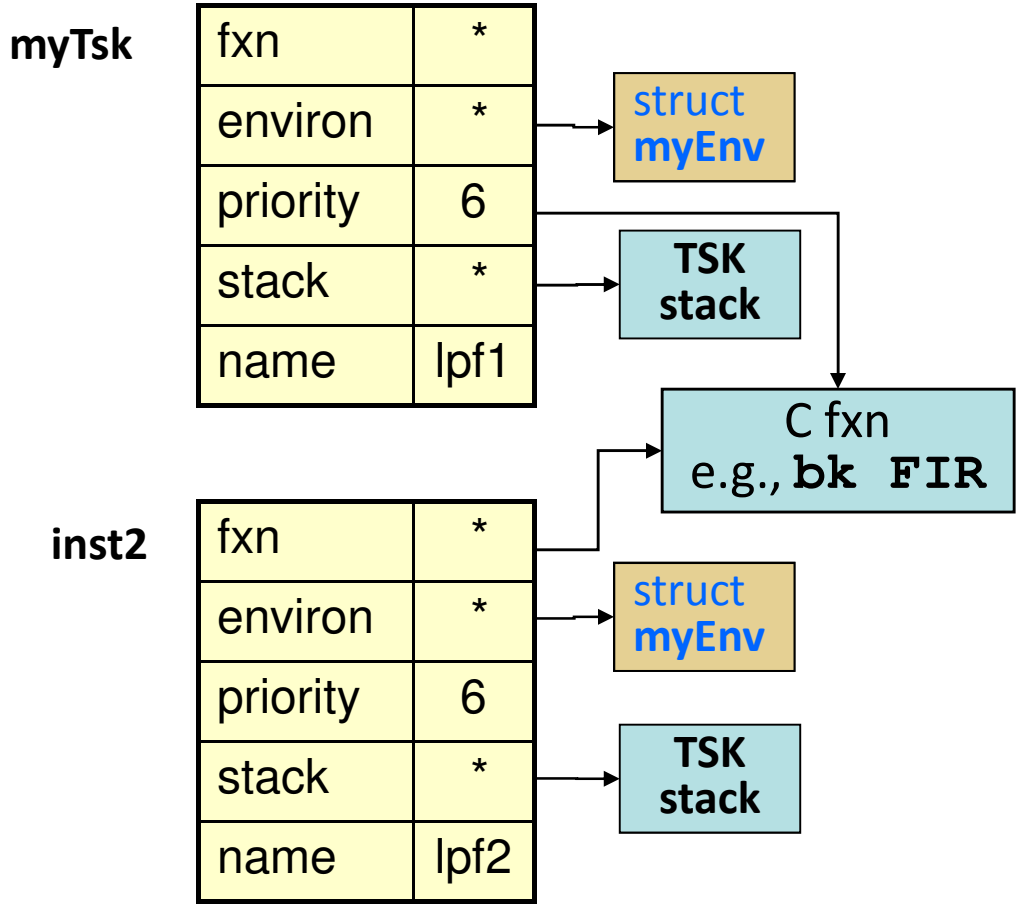
2 **Configure Task: Object name, function, priority, stack size**



Task Object Concepts

Task object:

- Pointer to task function
- Priority: changable
- Pointer to task's stack
  - Stores local variables
  - Nested function calls
  - makes blocking possible
  - Interrupts run on the system stack
- Pointer to text name of TSK
- Environment: pointer to *user defined* structure:




```
Task_setenv(Task_self(),&myEnv);

hMyEnv = Task_getenv(&myTsk);
```

Outline

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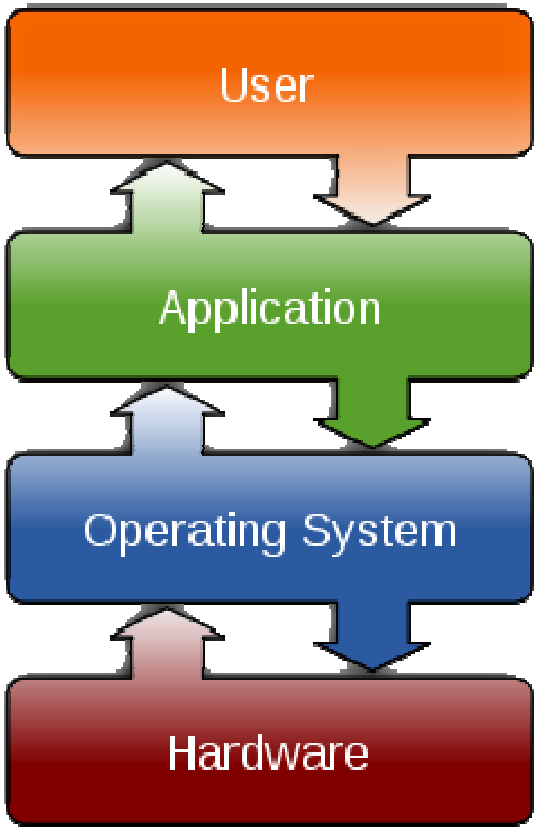
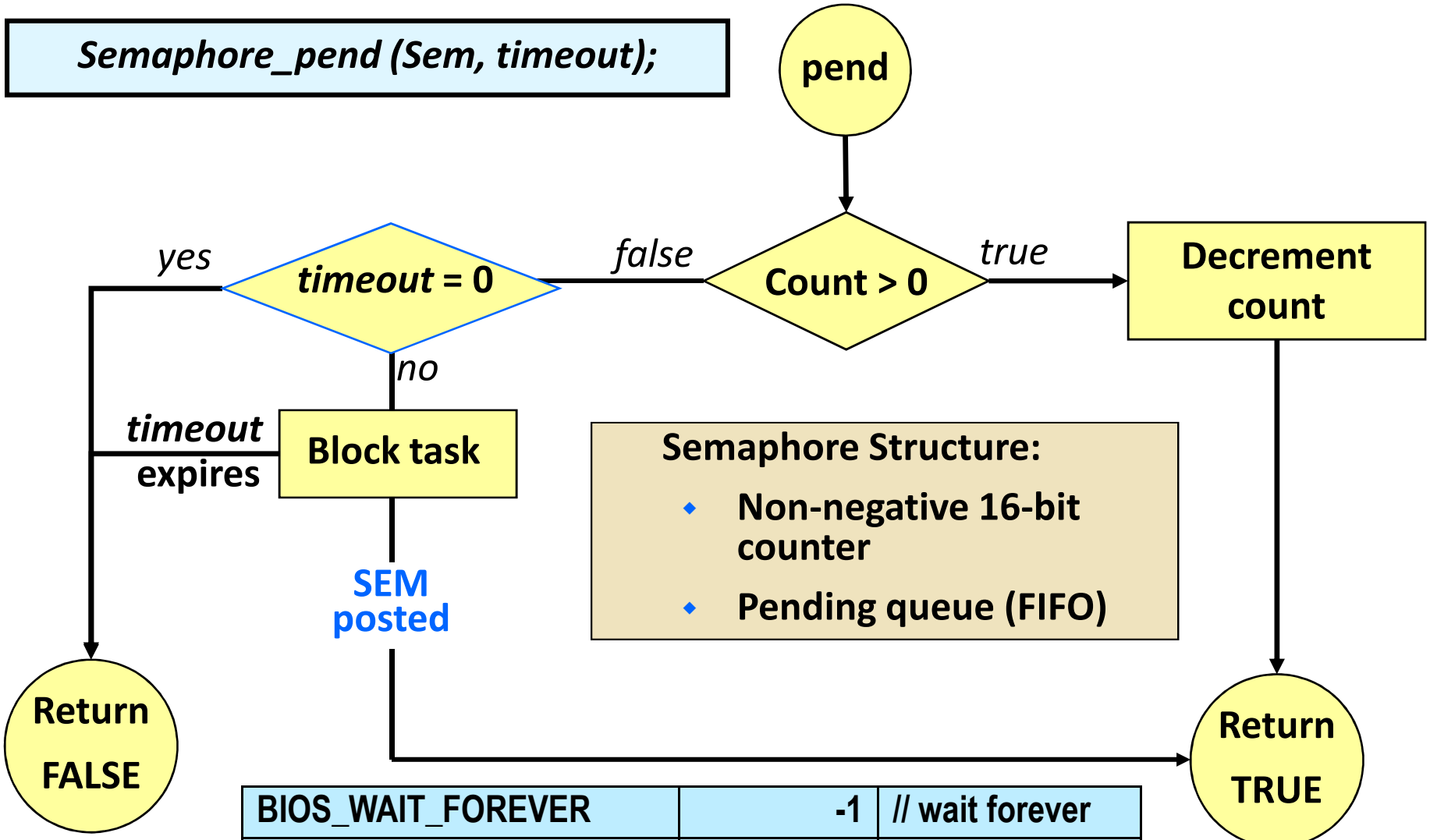
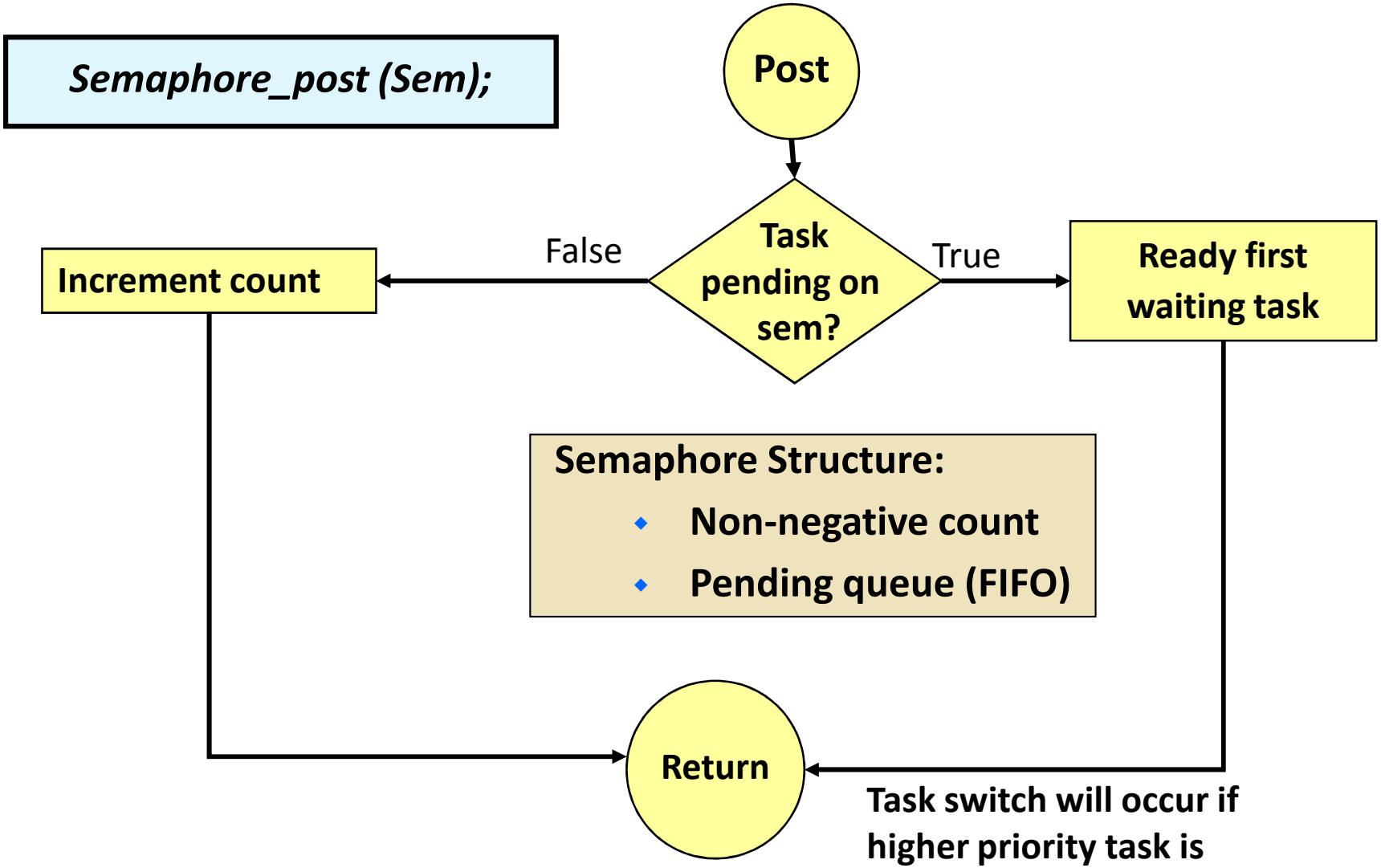


Semaphore Pend



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

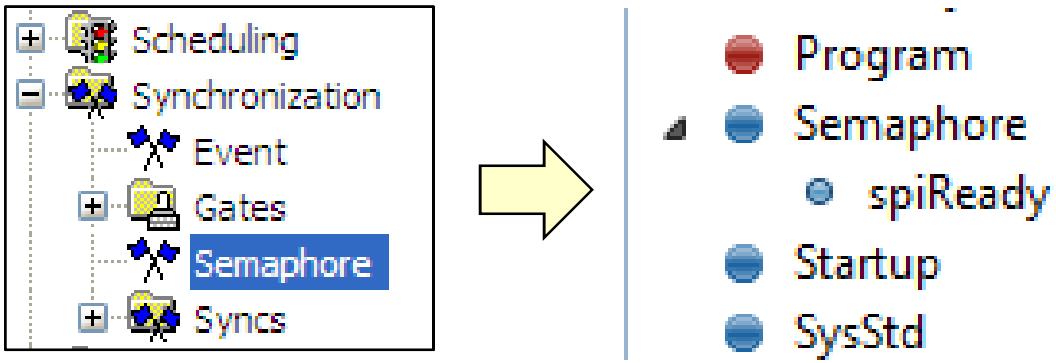
Semaphore Post



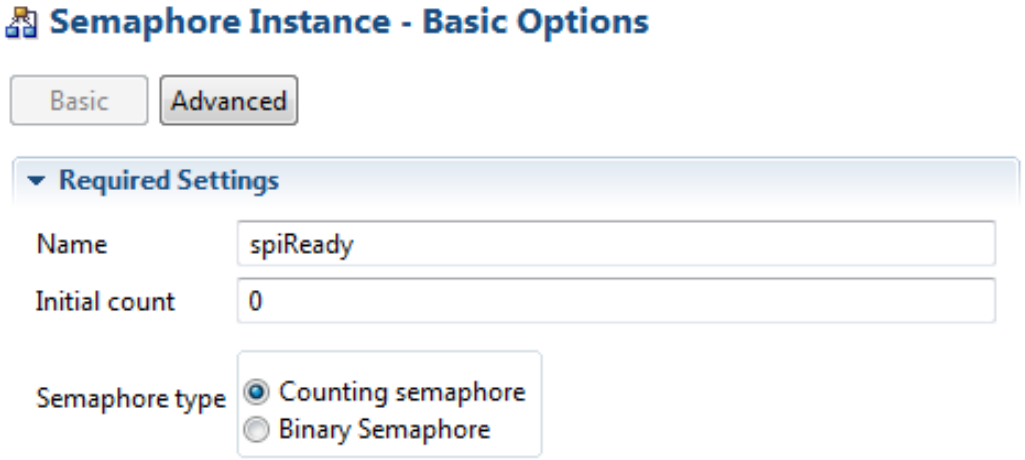
Configuring a Semaphore: Statically via GUI

Example: Create *spiReady*, 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?