07: Turning the while(1) loop into RTCS: Run-to-Completion Non-Preemptive Prioritized Scheduler

Improving the Infinite Loop Scheduler (Cyclic Executive)

- Features
  - Helps modularity by supporting tasks
  - Gives all tasks a chance to run (round-robin)
- Limitations
  - Task function name is hard-coded in scheduler function – *separation of functionality*
  - Task makes decision whether to do its work – *separation of functionality*
  - All tasks have same priority, run in fixed order
  - All tasks run at same rate
    - Each gets one chance to do its work per scheduler loop iteration
  - Tasks cannot preempt each other (sequential, not concurrent execution)

```
void Scheduler(void) {
    while (1) {
       Task_Foo();
       Task_Bar();
       Task_Service_UART();
    }

}

void Task_Service_UART(void) {
   if (UART_received_data) {
        // do task work
   }
   return;
}
```

Improving the Cyclic Executive (Infinite Loop Scheduler)

- Starting point
  - Each task returns early if it has no work to do
  - Task is making this run decision

```
void Scheduler(void) {
    while (1) {
       Task_Foo();
       Task_Bar();
       Task_Service_UART();
    }

}

void Task_Service_UART(void) {
   if (UART_received_data) {
        // do task work
   }
   return;
}
```

Basic Scheduler

Task Code
Scheduler Code
Scheduler Data

Task Code
Scheduler Code
Scheduler Data

```
void Scheduler(void) {
  while (1) {
    Task_Foo();
    Task_Bar();
  }
}
```

```
void Task_Foo(void) {
  if (run_Foo > 0) {
    run_Foo--;
    // do the Foo work
  }
}
```

```
void Task_Bar(void) {
  if (run_Bar > 0) {
    run_Bar--;
    // do the Bar work
  }
}
```

```
/* Globals for
   scheduling */
int run_Foo;
int run_Bar;
```

Move Decision to Work from Task into Scheduler

```
void Scheduler(void) {
   while (1) {
      if (run_Foo) {
         run_Foo--;
         Task_Foo();
      }
      if (run_Bar) {
         run_Bar--;
         Task_Bar();
      }
   }
}
```

```
void Task_Foo(void) {
   // do the Foo work
}
```

```
/* Globals for
   scheduling */
int run_Foo;
int run_Bar;
```

```
void Task_Bar(void) {
   // do the Bar work
}
```

Generalize the Scheduler with a Table (1)

```
/* Globals for
   scheduling */
int run_Foo;
int run_Bar;

typedef struct {
   int ReleasesPending;
   void (*Task)(void);
} TaskTableEntry;

TaskTableEntry Task_Table[3];
```

Sched Table

	ReleasesPending	Task (Function Pointer)
0	2	Task_Foo
1	1	Task_Bar
2	0	

```
void Task_Foo(void) {
   // do the Foo work
}

void Task_Bar(void) {
   // do the Bar work
}
```

TP = (&) Task_Table; TP→Task();

- Change run_* to ReleasesPending
  - >0? Need to run (release) the task
  - Count how many run requests have been made but not yet started
- "Task" field is pointer to task's root function

Generalize the Scheduler with a Table (2)

```
void Scheduler(void) {
    int i; // Current entry in task table
    while (1) {
       for (i=0; i<NTASKS; i++) {
           if (Task_Table[i].ReleasesPending > 0) { // If run is requested
               Task_Table[i].ReleasesPending--;       // Decrement request count
               Task_Table[i].Task();                  // Run the task
           }
       }
    }
}
```

	ReleasesPending	Task (Function Pointer)
0	~~2~~ ~~1~~ 0	Task_Foo
1	~~1~~ 0	Task_Bar
2	0	

```
void Task_Foo(void) {
    // do the Foo work
}
```

```
void Task_Bar(void) {
    // do the Bar work
}
```

Foo	Bar	Foo

Scheduler

Example of Scheduler Operation

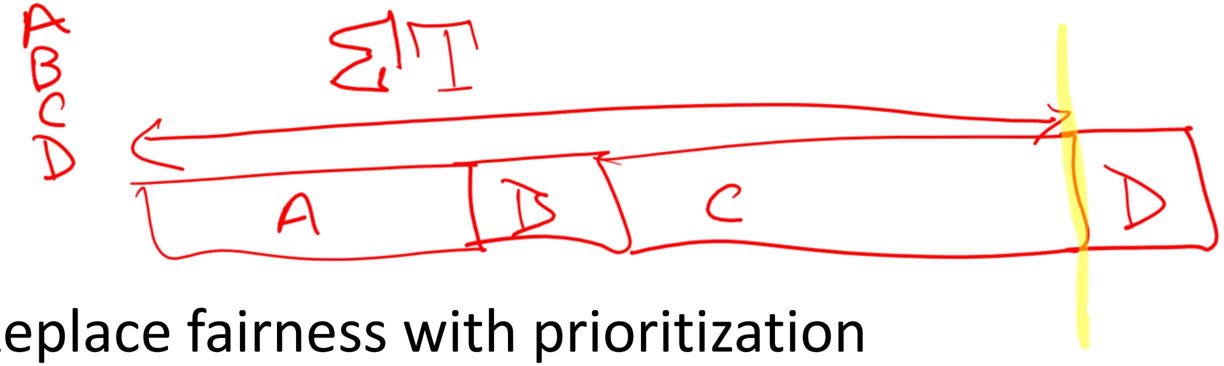
```
void Scheduler(void) {
    int i; // Current entry in task table
    while (1) {
       for (i=0; i<NTASKS; i++) {
            if (Task_Table[i].ReleasesPending > 0) { // If run is requested
                Task_Table[i].ReleasesPending--;      // Decrement request count
                Task_Table[i].Task();                 // Run the task
            }
       }
    }
}
```

Foo (0) ReleasesPending	2 1 0
Bar (1) ReleasesPending	1 0
Scheduler Activity	0? 1? 2? 0? 1? 2? 0? 1? 2?
Task Executing	Foo Bar Foo

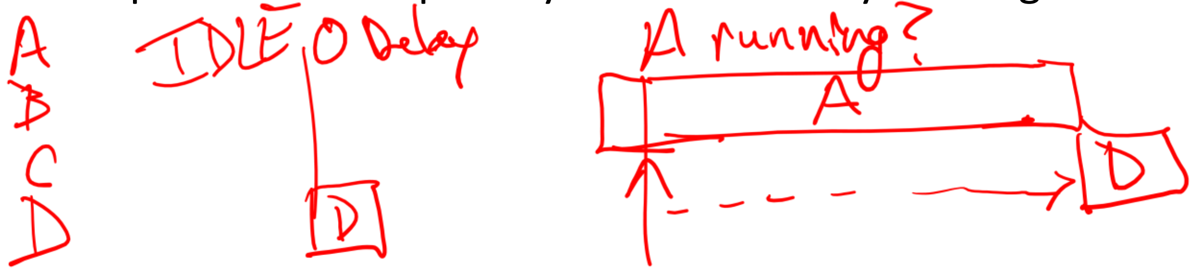
Timing Interference Between Tasks

ReleasesPending > 0

- Fair scheduling
  - Scheduler takes turns running ready tasks, giving each one run per scheduling cycle
  - Each task's run is delayed by all other ready tasks



- Replace fairness with prioritization
  - Scheduler runs highest priority ready task
  - Timing interference of lower-priority tasks is mostly eliminated
    - Exception: if lower-priority task is currently running



Add Priorities to Scheduler Operation

- After a task finishes running, have scheduler start at top of table again
- Use break statement to exit for loop

```
void Scheduler(void) {
    int i; // Current entry in task table
    while (1) {
        for (i=0; i<NTASKS; i++) {
            if (Task_Table[i].ReleasesPending > 0) { // If run is requested
                Task_Table[i].ReleasesPending--;        // Decrement request count
                Task_Table[i].Task();                   // Run the task
                break;                                  // Exit for loop
            }
        }
    }
}
```

Foo (0) ReleasesPending	2 – 1 — 0 —
Bar (1) ReleasesPending	1 — 0
Scheduler Activity	0? 0? 0? 1? 0?1?2?0?1?2?
Task Executing	Foo Foo Bar

Summary of Key Scheduler Features (so far)

- Source code in RTCS\RTCS.[ch]
- Finish the current task before you start another
  - "Run to completion" = task only yields control to scheduler at end of its root function.
  - Tasks aren't concurrent (unless we use FSMs).
  - One task can't preempt another task.
  - With these restrictions, we can still call tasks as subroutines, so only need one stack

- Interrupts operate as expected
  - Return control to previously executing function/task
- If there is more than one task to start, run the highest priority task first
  - Use an array of task descriptions (task table)
  - Place highest priority tasks at top
  - Start at *top* of task table whenever looking for a task to run
- If a task is ready to run, then scheduler will run it eventually, unless system is overloaded with work

Current Code to Run the Scheduler

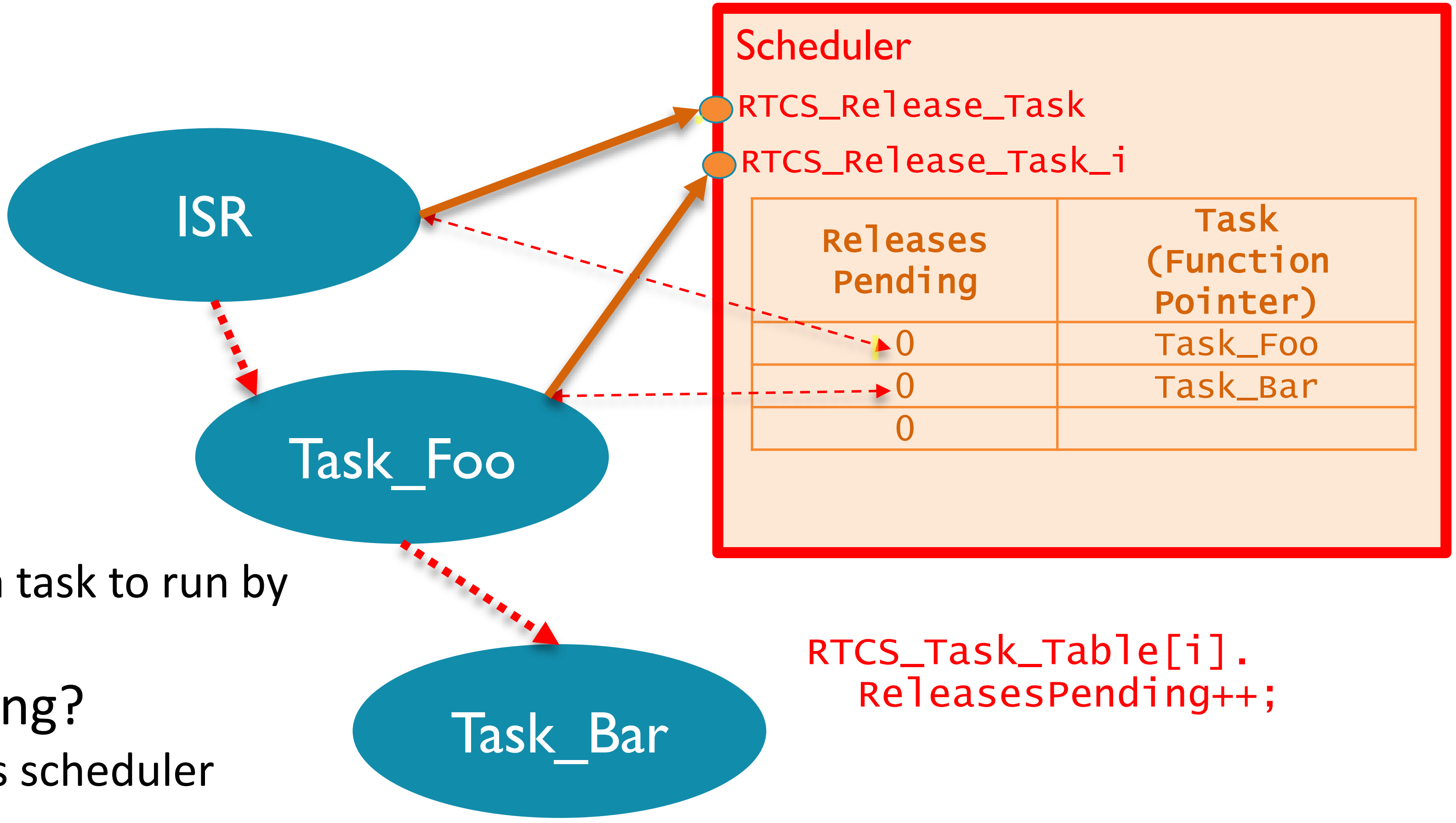
RP >0

```
void RTCS_Run_Scheduler(void){
  int i;
  while (1) {
    // start at top of table to find highest priority ready task
    for (i=0; i<RTCS_NUM_TASKS; i++) {
      if ((RTCS_Task_Table[i].Task != 0) &&
      (RTCS_Task_Table[i].ReleasesPending > 0)) {
        RTCS_Task_Table[i].ReleasesPending--;
        RTCS_Task_Table[i].Task();
        break; // Priority! Exit from for loop, start at top of table again
      }
    }
  }
}
```

- Note: added safety check for null Task pointer

Triggering Tasks with Events

- How can we trigger tasks to run?
  - Who **increments** ReleasesPending?
- Example
  - ISR triggers Task_Foo
  - Task_Foo triggers Task_Bar
- Event-Triggering
  - Tasks and ISRs can request for a task to run by incrementing *ReleasesPending*
- How to access ReleasesPending?
  - Dangerous and sloppy to access scheduler table directly
  - Instead access through an API call (adds range checks, other benefits)
    - RTCS_Release_Task, RTCS_Release_Task_i



API for Triggering Tasks

```
int RTCS_Release_Task_i(int i) {
  if (i < RTCS_NUM_TASKS) {
    if (RTCS_Task_Table[i].Task != 0) {
        RTCS_Task_Table[i].ReleasesPending++;
        return 1;
    }
  }
  return 0;
}
```

```
int RTCS_Find_Task_Priority(void (*task)(void)) {
  int i;
  for (i=0; i<RTCS_NUM_TASKS; i++) {
    if (RTCS_Task_Table[i].Task == task) {
        return i;
    }
  }
  return -1;
}
```

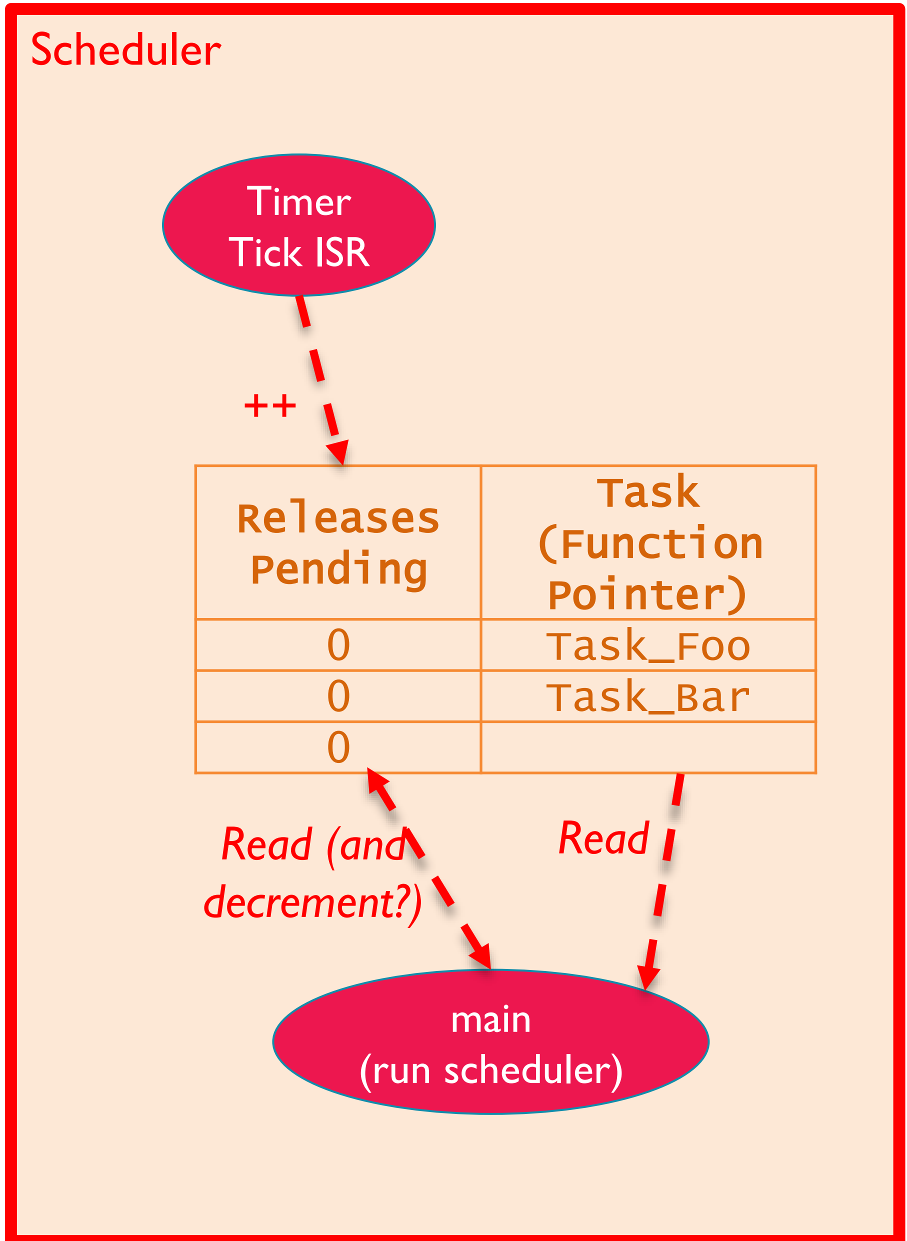
Task_Foo

```
int RTCS_Release_Task(void (*task)(void)) {
  int i;
  i = RTCS_Find_Task_Priority(task);
  if ((i >= 0) && (i<RTCS_NUM_TASKS)) {
        RTCS_Task_Table[i].ReleasesPending++;
        return 1;
  }
  return 0;
}
```

- Can specify task by table location or by function pointer

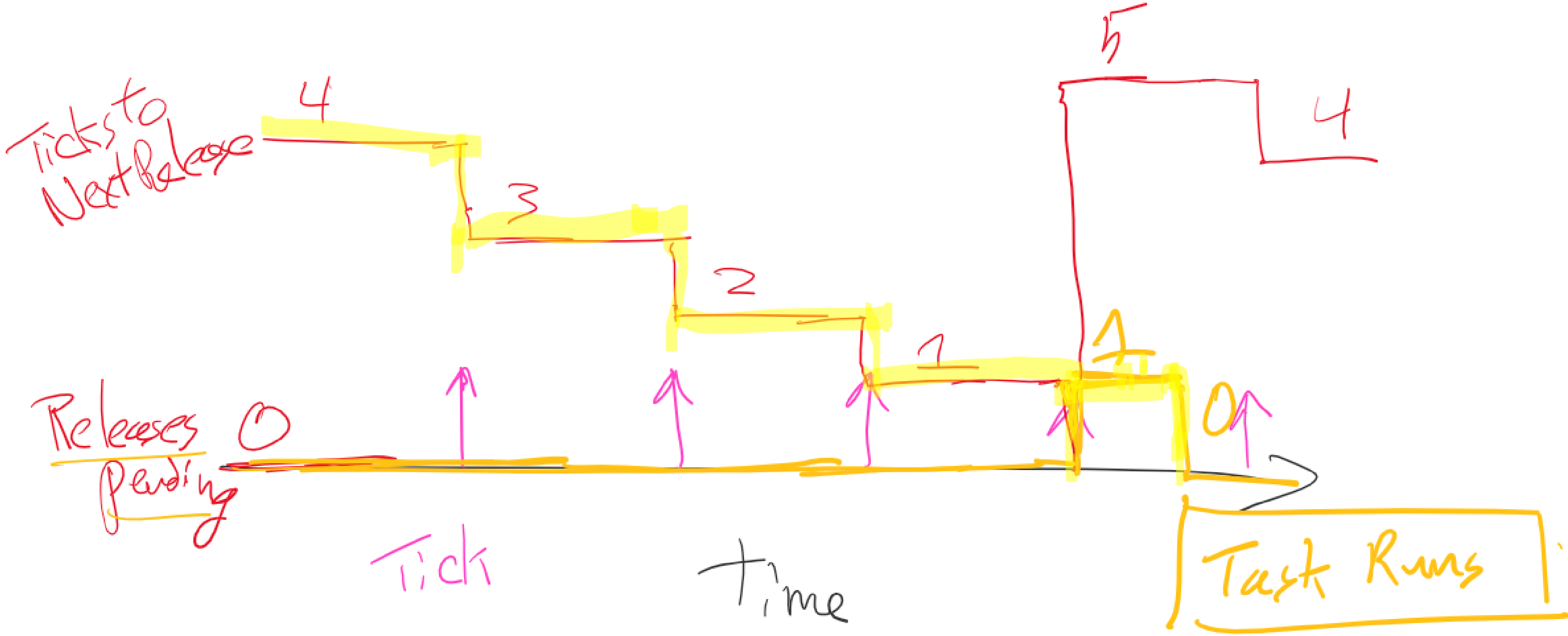
Adding Periodic Triggering for Tasks

- Current solution requires task or ISR to trigger each task run (release)
  - Awkward, limited
- Let's add time-based scheduling triggers
  - "Run this task every 18 ms starting ASAP"
  - Could also do
    - "Run this task after 13 ms, and then every 13 ms."
- Use a periodic scheduler tick function
  - Use hardware timer to trigger ISR every 1 ms
  - Scheduler tick function
    - Tracks elapsed time
    - Increments a task's *ReleasesPending* count if it's time to run the task
- Remember, scheduler will run any tasks with ReleasesPending > 0



Making a Task Periodic

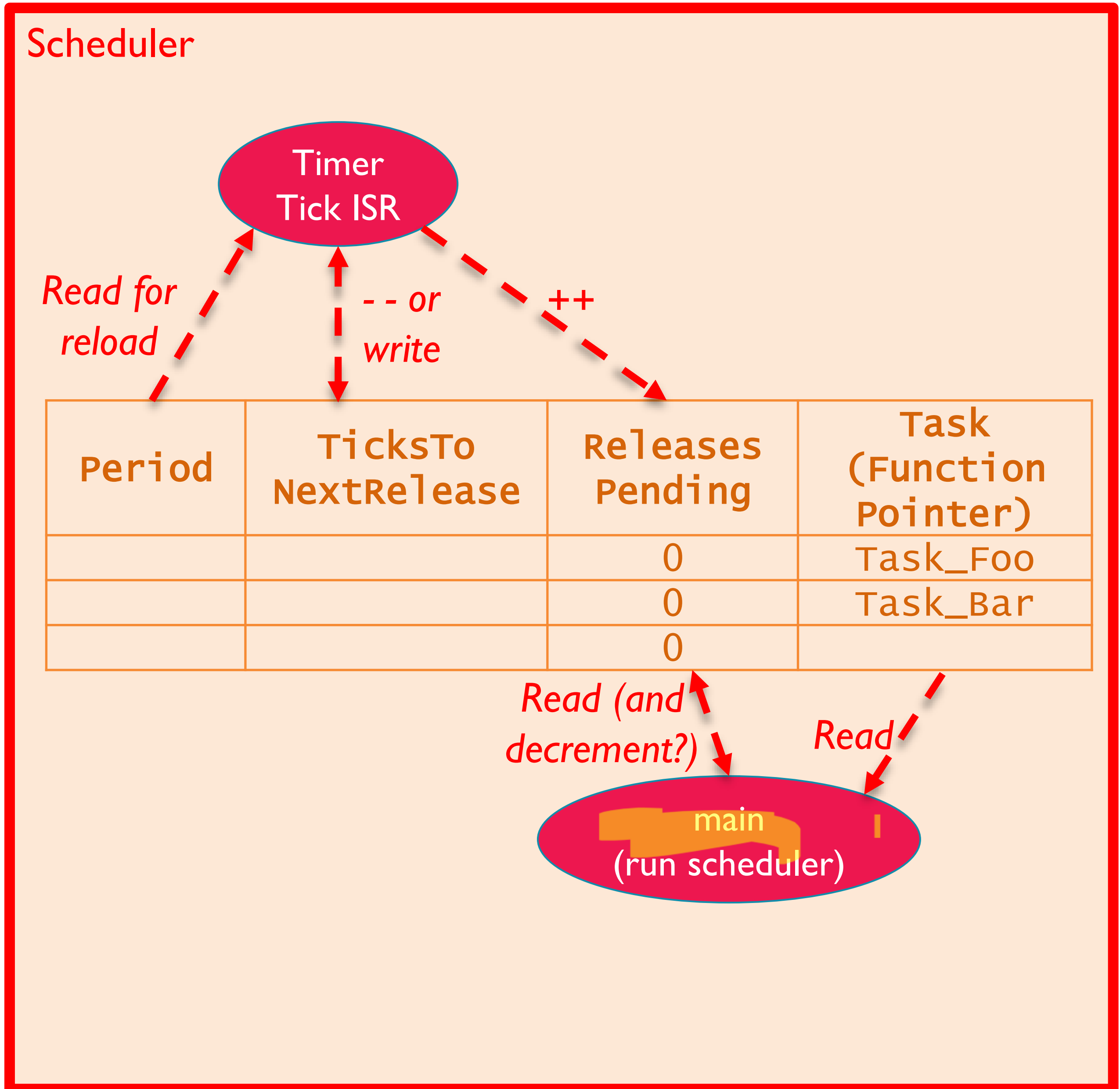
- On each tick, Timer Tick function decrements ticks remaining until next release
- When ticks remaining reaches zero, Timer Tick ISR increments ReleasesPending
- RTCS_Run_Scheduler can now run task



Adding Periodic Triggering for Tasks

- Task table needs more information
  - Ticks to next release (TTNR)
  - Task period, to reload TTNR value
- Timer Tick Function
  - Decrements delay *TicksToNextRelease*
  - If TTNR reaches zero,
    - Reload it with *Period*
    - Increment *RunRequestsPending*

- **Scheduler** will run tasks with *ReleasesPending* > 0



Code to Update Task Table on Each Tick

```
void RTCS_Timer_Tick(void){
  int i;

  PTB->PSOR = MASK(DEBUG_RTCS_POS); // Debug signal
  RTCS_Num_Ticks++;
  for (i=0; i<RTCS_NUM_TASKS; i++) {
   if ((RTCS_Task_Table[i].Task!=0) && (RTCS_Task_Table[i].TicksToNextRelease>0)) {
    if (--RTCS_Task_Table[i].TicksToNextRelease == 0) {
      RTCS_Task_Table[i].ReleasesPending++;
      RTCS_Task_Table[i].TicksToNextRelease = RTCS_Task_Table[i].Period;
    }
   }
  }
  PTB->PCOR = MASK(DEBUG_RTCS_POS); // Debug signal
}
```

pre-decrement

Example of Scheduler Operation with Periodic Tasks

Index	Task	TicksToNextRelease	ReleasesPending	Period
0	A	2	0	4
1	(empty)	0	0	
2	(empty)	0	0	
3	B	4	0	8

A TicksTo NextRelease									
A ReleasesPending	0								
B TicksTo NextRelease									
B ReleasesPending	0								
Tick Timer ISR									
Scheduler Act.									
Task Executing									

Example of Scheduler Operation with Periodic Tasks

Index	Task	TicksToNextRelease	ReleasesPending	Period
0	A	~~2~~ ~~1~~ ~~0~~ ~~4~~ ~~3~~ ~~2~~	~~0~~ 1	4
1	(empty)	0	0	
2	(empty)	0	0	
3	B	~~4~~ ~~3~~ ~~2~~ ~~1~~ 8	0	8

A TicksTo NextRelease	2	1		~~0~~ 4	4	3		2	
A ReleasesPending	0			1	~~1~~ 0				
B TicksTo NextRelease	4	3		2		1		~~0~~ 8	
B ReleasesPending	0							1	~~1~~ 0
Tick Timer ISR									
Scheduler Act.	0? 1? 2? 3?		0? 1? 2? 3? ... 2?		3? 0?		0? 1? 2? 3? ? ? ?		1? 2? 3? ?
Task Executing					A		A		B

Enable/Disable Task

- Useful to be able to enable or disable tasks in scheduler
  - Need a new field in the scheduler table
  - Need to update tests in scheduler and timer tick functions
  - Need related API Enable/Disable functions

```
typedef struct {
  void (*Task)(void);
  uint16_t Period;
  uint16_t TicksToNextRelease;
  uint8_t RunRequestsPending;
  uint8_t Enabled;
} RTCS_TASK_ENTRY;
```

```
// RTCS_Run_Scheduler
   if ((RTCS_Task_Table[i].Task != 0) && (RTCS_Task_Table[i].Enabled) &&
      (RTCS_Task_Table[i].RunRequestsPending > 0)) {

// RTCS_Timer_Tick
   if ((RTCS_Task_Table[i].Task != 0) && (RTCS_Task_Table[i].Enabled) &&
     (RTCS_Task_Table[i].TicksToNextRelease > 0)) {
```

RTCS Scheduler Configuration

RTCS.h

```
#define RTCS_MAX_TASKS 10    // Set maximum number of tasks to be used in system
```

gpio_defs.h

```
#define DEBUG_RTCS_POS     0 // J10 pin 2
```