Fixed scheduling

In advance a priori, during the design phase
- Thread sequence
- Allocated time-slices

Like
- creating the city bus schedule, or
- routing packages through a warehouse
- Construction project.

Fundamental principles
- Gather reliable information about the tasks
- Build slack into the plan; expect delays; anticipate problems
- Just in time

What we do first is create a list of tasks to perform
1. Assigning a priority to each task,
2. Defining the resources required for each task,
3. Determining how often each task is to run, and
4. Estimating how long each task will require to complete.

Consider resources required versus available
- Processor
- Memory
- I/O channels
- Data

Objectives
- guarantee performance (latency, bandwidth)
- utilization
- Maximize profit

Strategy
- schedule highest priority tasks first,
  - 100% satisfaction guaranteed
- then schedule all real-time tasks
  - shuffle the assignments like placing pieces in a puzzle
  - maximizing objectives
- The tasks that are not real-time can be scheduled in the remaining slots.

Design example
- finite state machine (**`FSM`**),
- proportional-integral-derivative controller (**`PID`**),
- data acquisition system (**`DAS`**).
- non-real-time task, **`PAN`**

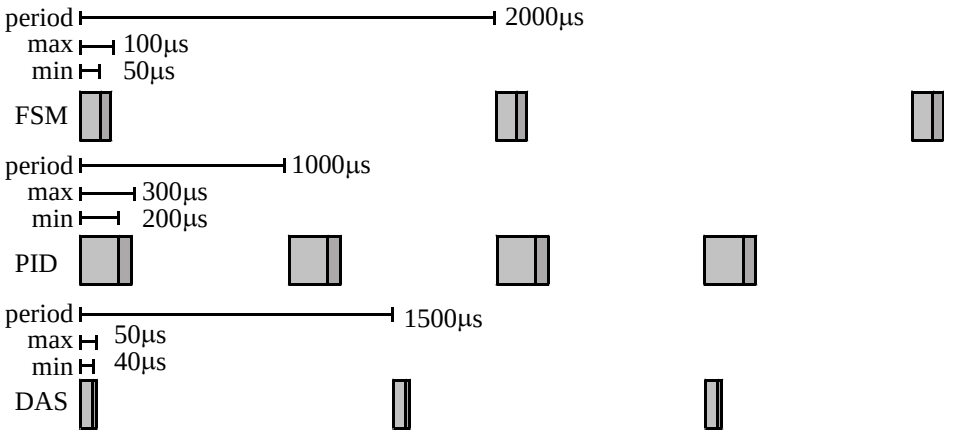


Figure 4.16. Real-time specifications for these three tasks.

$$\sum_{i=0}^{n-1}\frac{E_i}{T_i}=\sum\frac{100}{2000}+\frac{300}{1000}+\frac{50}{1500}=0.38\le n\left(2^{1/n}-1\right)=3\left(2^{1/3}-1\right)=0.78$$

To guarantee tasks will run on time,
consider the maximum times

Process
Look for a repeating pattern least common multiple of 2000, 1000, and 1500
time-shift the second and third tasks
Avoid overlaps,
start with the most frequent task (or most frequent task)

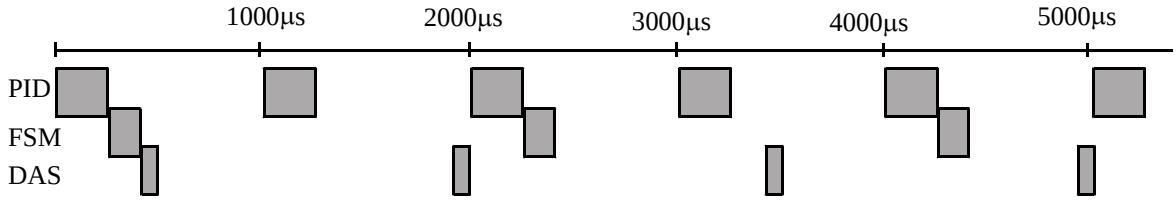


Figure 4.17. Repeating pattern to schedule these three real-time tasks.

How it works

OS_Suspend
Cooperatively stops a real-time task
Runs a non real-time task

Timer interrupt
Occurs when it is time to run a real-time task
Suspends a non-real-time task
Runs the next real-time task

```
//******************FSM*************************
void FSM(void){ StatePtr Pt;   unsigned char in;
  Pt = SA;                  // Initial State
  for(;;) {
    OS_Suspend();           // Runs every 2ms
    Port_Out(Pt->Out);      // Output depends on the current state
```

```
    in = Port_In();
    Pt = Pt->Next[in];     // Next state depends on the input
  }
}
//******************PID*************************
void PID(void){ unsigned char speed,power;
  PID_Init();              // Initialize
  for(;;) {
    OS_Suspend();          // Runs every 1ms
    speed = PID_In();      // read tachometer
    power = PID_Calc(speed);
    PID_Out(power);        // adjust power to motor
  }
}
//******************DAS*************************
void DAS(void){ unsigned char raw;
  DAS_Init();            // Initialize
  for(;;) {
    OS_Suspend();        // Runs every 1.5ms
    raw = DAS_In();      // read ADC
    Result = DAS_Calc(raw);
  }
}
//******************PAN*************************
void PAN(void){ unsigned char input;
  PAN_Init();            // Initialize
  for(;;) {
    input = PAN_In();    // front panel input
    if(input){
      PAN_Out(input);    // process
    }
  }
}
```

Program 4.19. Four user threads.

```
struct TCB{
  unsigned long *StackPt;       // Stack Pointer
  unsigned long MoreStack[84];  // 400 bytes of stack
  unsigned long InitialReg[14]; // R4-R11,R0-R3,R12,R14
  unsigned long InitialPC;      // pointer to program to execute
  unsigned long InitialPSR;     // 0x01000000
};
typedef struct TCB TCBType;
TCBType *RunPt;            // thread currently running
#define TheFSM &sys[0]     // finite state machine
#define ThePID &sys[1]     // proportional-integral-derivative
#define TheDAS &sys[2]     // data acquisition system
#define ThePAN &sys[3]     // front panel
TCBType sys[4]={
  { &sys[0].InitialReg[0],{ 0}, FSM, 0x01000000},
  { &sys[1].InitialReg[0],{ 0}, PID, 0x01000000},
  { &sys[2].InitialReg[0],{ 0}, DAS, 0x01000000},
  { &sys[3].InitialReg[0],{ 0}, PAN, 0x01000000}
};
```

Program 4.20. The thread control blocks.

```
struct Node{
  struct Node *Next;        // circular linked list
  TCBType *ThreadPt;        // which thread to run
  unsigned short TimeSlice; // how long to run it
};
typedef struct Node NodeType;
NodeType *NodePt;
NodeType Schedule[22]={
{ &Schedule[1], ThePID, 300}, // interval     0,  300
{ &Schedule[2], TheFSM, 100}, // interval   300,  400
{ &Schedule[3], TheDAS,  50}, // interval   400,  450
{ &Schedule[4], ThePAN, 550}, // interval   450, 1000
{ &Schedule[5], ThePID, 300}, // interval  1000, 1300
{ &Schedule[6], ThePAN, 600}, // interval  1300, 1900
{ &Schedule[7], TheDAS,  50}, // interval  1900, 1950
{ &Schedule[8], ThePAN,  50}, // interval  1950, 2000
{ &Schedule[9], ThePID, 300}, // interval  2000, 2300
{ &Schedule[10],TheFSM, 100}, // interval  2300, 2400
{ &Schedule[11],ThePAN, 600}, // interval  2400, 3000
{ &Schedule[12],ThePID, 300}, // interval  3000, 3300
{ &Schedule[13],ThePAN, 100}, // interval  3300, 3400
{ &Schedule[14],TheDAS,  50}, // interval  3400, 3450
{ &Schedule[15],ThePAN, 550}, // interval  3450, 4000
{ &Schedule[16],ThePID, 300}, // interval  4000, 4300
{ &Schedule[17],TheFSM, 100}, // interval  4300, 4400
{ &Schedule[18],ThePAN, 500}, // interval  4400, 4900
{ &Schedule[19],TheDAS,  50}, // interval  4900, 4950
{ &Schedule[20],ThePAN,  50}, // interval  4950, 5000
{ &Schedule[21],ThePID, 300}, // interval  5000, 5300
{ &Schedule[0], ThePAN, 700}  // interval  5300, 6000
};
```

Program 4.21. The scheduler defines both the thread and the duration.

Results (time measurements in 1μs units)

Finite State Machine			PID Controller			DAS		
1	40637		10	39338		100	39237	
1	42637	2000	10	40338	1000	100	40738	1501
1	44637	2000	10	41338	1000	100	42238	1500
1	46638	2001	10	42338	1000	100	43738	1500
1	48638	2000	10	43337	999	100	45238	1500
1	50638	2000	10	44338	1001	100	46737	1499
1	52637	1999	10	45338	1000	100	48238	1501
1	54637	2000	10	46338	1000	100	49738	1500
1	56637	2000	10	47338	1000	100	51237	1499
1	58638	2001	10	48338	1000	100	52738	1501
1	60637	1999	10	49338	1000	100	54238	1500
1	62638	2001	10	50338	1000	100	55738	1500
1	64637	1999	10	51338	1000	100	57238	1500
1	1102	2001	10	52338	1000	100	58738	1500
1	3101	1999	10	53338	1000	100	60238	1500

1	5102	2001	10	54338	1000	100	61738	1500
1	7102	2000	10	55338	1000	100	63238	1500
1	9102	2000	10	56338	1000	100	64738	1500
1	11101	1999	10	57337	999	100	702	1500
1	13101	2000	10	58338	1001	100	2202	1500
1	15101	2000	10	59338	1000	100	3702	1500
1	17102	2001	10	60338	1000	100	5202	1500
1	19102	2000	10	61338	1000	100	6702	1500
1	21102	2000	10	62337	999	100	8201	1499
1	23101	1999	10	63338	1001	100	9701	1500
1	25101	2000	10	64338	1000	100	11202	1501
1	27101	2000	10	65338	1000	100	12702	1500
1	29102	2001	10	802	1000	100	14202	1500
1	31101	1999	10	1802	1000	100	15702	1500

Question: *Could we solve this problem with regular periodic interrupts?*
See data sheet Section 11.3.4 Synchronizing GP Timer Blocks

Rate Monotonic Scheduling Theorem

- All n tasks are periodic
  - Priority based on period of T_i
  - Maximum execution time E_i
- No synchronization between tasks
- Execute highest priority task first

$$\sum \frac{E_i}{T_i} \le n\left(2^{1/n} - 1\right) \rightarrow \ln(2)$$

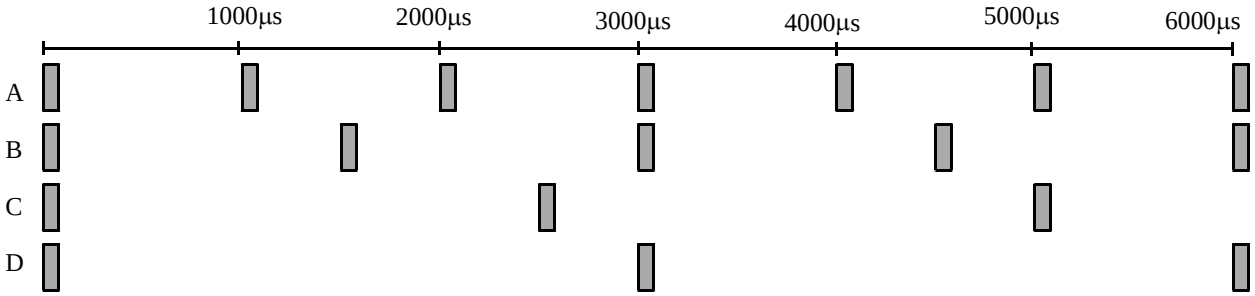
Algorithm to find schedule with minimum jitter
Design parameters
Period for each task T_i
Maximum execution for each task E_i
Fundamental issues
Find the largest Δt, and convert T_i and E_i specifications to integers
Find time at which the pattern repeats, least common multiple of T_i

Code posted on class web site and here http://codepad.org/dGy6fk9P
http://users.ece.utexas.edu/~valvano/EE345M/ScheduleFinder.c

Example 1

Task A runs every 1.0 ms T1=1.0ms, maximum time is 0.1ms
Task B runs every 1.5 ms T2=1.5ms, maximum time is 0.1ms
Task C runs every 2.5 ms T3=2.5ms, maximum time is 0.1ms
Task D runs every 3.0 ms T4=3.0ms, maximum time is 0.1ms

Time quanta = **Δt** = 0.1 ms
LCM 10, 15, 25 and 30 is 150
Let n be the number of tasks
Search space is about (T2/**Δt**)*(T3/**Δt**)* … *(Tn/**Δt**)



Time quanta = 0.1ms, pattern repeats every 15ms
E1/T1 + E2/T2 + E3/T3 + E4/T4 = 0.24
Search space is about (15)*(25)*(30)=11250 possible schedules

Schedule Task A at times 0,1,2... times n*10 (units 0.1ms)
Schedule Task B at times j,j+1.5,j+3.0,... times n*15 + j
Schedule Task C at times k,k+2.5,k+5.0,... times n*25 + k
Schedule Task D at times l,l+3,l+6, ... times n*30 + l

Inputs to the **`ScheduleFinder`** are

desired four periods 1, 1.5, 2.5 and 3 ms
maximum execution time 0.1 ms for each

Outputs of the **`ScheduleFinder`** are

`j` slide factor (in 0.1ms units) for Task B
`k` slide factor (in 0.1ms units) for Task C
`l` slide factor (in 0.1ms units) for Task D
`jitter` is the number of missed tasks

Performance criteria minimum overlap (jitter) call it **`ScheduleFinder(10,15,25,30)`**

```
#define MAX 150
char Times[MAX]; // filled with spaces
char bestTimes[MAX];
int bestj,bestk,bestl;
int ScheduleFinder(int ta, int tb, int tc, int td){
  int i,j,k,l; int jitter=0;
  int thei,thejitter;   // find schedule for task b with min jitter
  jitter = 100000;
  for(j=0; j<tb; j++){      // slide factor task B
    for(k=0; k<tc; k++){    // slide factor task C
      for(l=0; l<td; l++){  // slide factor task D
        for(i=0; i<MAX; i++) Times[i] = ' '; // space means time not used
        for(i=0; i<MAX; i=i+ta) Times[i] = 'a'; // schedule task a
        thejitter = 0;
```

```
        for(i=j; i<MAX; i=i+tb){
          if(Times[i]== ' '){
            Times[i] = 'b'; // schedule B no jitter
          } else{
            thei = i;  // search for place to schedule
            do{
              thei++;
              thejitter++;
            }
            while(Times[thei]!= ' '&&thei<MAX);
            if(thei<MAX) Times[thei] = 'B'; // schedule B with jitter
          }
        }
        for(i=k; i<MAX; i=i+tc){
          if(Times[i]== ' '){
            Times[i] = 'c'; // schedule C no jitter
          } else{
            thei = i;  // search for place to schedule
            do{
              thei++;
              thejitter++;
            }
            while(Times[thei]!= ' '&&thei<MAX);
            if(thei<MAX) Times[thei] = 'C'; // schedule C with jitter
          }
        }
        for(i=l; i<MAX; i=i+td){
          if(Times[i]== ' '){
            Times[i] = 'd'; // schedule D no jitter
          } else{
            thei = i;  // search for place to schedule
            do{
              thei++;
              thejitter++;
            }
            while(Times[thei]!= ' '&&thei<MAX);
            if(thei<MAX) Times[thei] = 'D'; // schedule D with jitter
          }
        }
        if(thejitter<jitter){
          bestj = j;  bestk = k; bestl = l;
          jitter = thejitter;
          for(i=0; i<MAX; i++) bestTimes[i] = Times[i]; // best schedule
        }
      }
    }
  }
  return jitter;
}
```

```
abcd      a     b   a      c  ab d      a     b   a c       ab d      a
01234567890123456789012345678901234567890123456789012345678901234567890123456789012345678901234
 bc  a         ab d      a c   b   a         ab d   c   a     b   a
56789012345678901234567890123456789012345678901234567890123456789012345678901234567890123456789
```

Schedule Task A at times 0, 10, 20... times n*10 (units 0.1ms)
Schedule Task B at times 1, 16, 31,... times n*15 + 1
Schedule Task C at times 2, 27, 52,... times n*25 + 2
Schedule Task D at times 3, 33, 63,... times n*30 + 3

Jitter = 0

Example 2

Task A runs every 0.4 ms T1=0.4ms, maximum time is 0.1ms
Task B runs every 0.6 ms T2=0.6ms, maximum time is 0.1ms
Task C runs every 1.0 ms T3=1.0ms, maximum time is 0.1ms
Task D runs every 1.5 ms T4=1.5ms, maximum time is 0.1ms
Time quanta = 0.1ms, pattern repeats every 9ms
E1/T1 + E2/T2 + E3/T3 + E4/T4 = 0.58
Schedule Task A at times 0,4,8... times n*4 (units 0.1ms)
Schedule Task B at times j,j+6,j+12,... times n*6 + j
Schedule Task C at times k,k+10,k+20,... times n*10 + k
Schedule Task D at times l,l+15,l+30,... times n*15 + l
call **`ScheduleFinder(4,6,10,15)`**
Schedule Task A at times 0,4,8... times n*4 (units 0.1ms)
Schedule Task B at times 1,7,13,... times n*6 + 1
Schedule Task C at times 1,21,31,41... times n*10 + 1
Schedule Task D at times 14,29,44,... times n*15 + 14
Jitter = 5

```
abC a  ba  cabd a  bac  ab  ad baC  ab  ac baD  ab c
012345678901234567890123456789012345678901234567890
a  ba  dabC a  ba  cabd a  bac  ab  ad
234567890123456789012345678901234567890
```

Red means one time quanta late
Blue means two time quanta late (or one time quanta early)