What is SCHED_DEADLINE?

- A new scheduling class (Well since v3.14)
  - others are: SCHED_OTHER, SCHED_FIFO, SCHED_RR
- Constant Bandwidth Scheduler
- Earliest Deadline First
Other Schedulers

- **SCHED_OTHER**
  - Completely Fair Scheduler (CFS)
  - Uses “nice” priority
  - Each task gets a fair share of the CPU bandwidth

- **SCHED_FIFO**
  - First in, first out
  - Each task runs till it gives up the CPU or a higher priority task preempts it

- **SCHED_RR**
  - Like SCHED_FIFO but same prio tasks get slices of CPU
SCHED_RR (Round Robin)

CPU 1

RR Prio 5
50 %

RR Prio 5
50 %

CPU 2

RR Prio 5
100 %
Priorities

- You have two programs running on the same CPU
  - One runs a nuclear power plant
    - Requires 1/2 second out of every second of the CPU
  - The other runs a washing machine
    - Requires 50 millisecond out of every 200 milliseconds
  - Which one gets the higher priority?
Priorities

1/2 sec 1 sec

½ sec 1 sec
Priorities  Nuke > Washing Machine
Priorities: Nuke < Washing Machine

- ½ sec
- 1 sec
- ½ sec
- 1 sec
Rate Monotonic Scheduling (RMS)

- Computational time vs Period
- Can be implemented by SCHED_FIFO
- Smallest period gets highest priority
- Compute computation time (C)
- Compute period time (T)

\[ U = \sum_{i=1}^{n} \frac{C_i}{T_i} \]
Rate Monotonic Scheduling (RMS)

- Add a Dishwasher to the mix...
- Nuclear Power Plant: $C = 500\text{ms}$ $T=1000\text{ms}$
- Dishwasher: $C = 300\text{ms}$ $T = 900\text{ms}$
- Washing Machine: $C = 100\text{ms}$ $T = 800\text{ms}$

$$U = \frac{500}{1000} + \frac{300}{900} + \frac{100}{800} = .958333$$
Rate Monotonic Scheduling (RMS)
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\[ U = \sum_{i=1}^{n} \frac{C_i}{T_i} \leq n(\sqrt[4]{2} - 1) \]
Rate Monotonic Scheduling (RMS)

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Rate Monotonic Scheduling (RMS)

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- Nuclear Power Plant: C = 500ms T=1000ms
- Dishwasher: C = 300ms T = 900ms
- Washing Machine: C = 100ms T = 800ms

\[
U = \frac{500}{1000} + \frac{300}{900} + \frac{100}{800} = 0.958333 \\
U \leq n(\sqrt[3]{2} - 1) = 3(\sqrt[3]{2} - 1) = 0.77976
\]
Rate Monotonic Scheduling (RMS)

\[ U = \sum_{i=1}^{n} \frac{C_i}{T_i} \leq n(\sqrt[n]{2} - 1) \]

\[ \lim_{n \to \infty} n(\sqrt[n]{2} - 1) = \ln 2 \approx 0.693147 \]
SCHED_DEADLINE

- Utilizes Earliest Deadline First (EDF)
- Dynamic priority
- The task with next deadline has highest priority

\[ U = \sum_{i=1}^{n} \frac{C_i}{T_i} = 1 \]
Earliest Deadline First (EDF)

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Earliest Deadline First (EDF)
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Earliest Deadline First (EDF)

:) HAPPY :)
Earliest Deadline First (EDF)
Earliest Deadline First (EDF)
Implementing SCHED\_DEADLINE in Linux

Constant Bandwidth Server (CBS)

\[
\frac{\text{remaining runtime}}{\text{scheduling deadline} - \text{current time}} > \frac{\text{runtime}}{\text{period}}
\]

scheduling deadline = current time + deadline

remaining runtime = runtime

Two new syscalls

- sched\_getattr(pid_t pid, struct sched\_attr *attr, unsigned int size, unsigned int flags)
  (Similar to sched\_getparam(pid_t pid, struct sched\_param *param)

- sched\_setattr(pid_t pid, struct sched\_attr *attr, unsigned int flags)
  (Similar to sched\_setparam(pid_t pid, struct sched\_param *param)
Implementing SCHED_DEADLINE

```c
struct sched_attr {
    u32 size;              /* Size of this structure */
    u32 sched_policy;      /* Policy (SCHED_*) */
    u64 sched_flags;       /* Flags */
    s32 sched_nice;        /* Nice value (SCHED_OTHER,
                              SCHED_BATCH) */
    u32 sched_priority;    /* Static priority (SCHED_FIFO,
                              SCHED_RR) */
    u64 sched_runtime;     /* Remaining fields are for SCHED_DEADLINE */
    u64 sched_deadline;
    u64 sched_period;
};
```
Implementing SCHED_DEADLINE

```c
struct sched_attr attr;

ret = sched_getattr(0, &attr, sizeof(attr), 0);
if (ret < 0)
    error();

attr.sched_policy = SCHED_DEADLINE;
attr.sched_runtime = runtime_ns;
attr.sched_deadline = deadline_ns;

ret = sched_setattr(0, &attr, 0);
if (ret < 0)
    error();
```
sched_yield()

- Most use cases are buggy
  - Most tasks will not give up the CPU

- SCHED_OTHER
  - Gives up current CPU time slice

- SCHED_FIFO / SCHED_RR
  - Gives up the CPU to a task of the SAME PRIORITY
  - Voluntary scheduling among same priority tasks
sched_yield()

- Buggy code!

    again:
    pthread_mutex_lock(&mutex_A);
    B = A->B;

    if (pthread_mutex_trylock(&B->mutex_B)) {
        pthread_mutex_unlock(&mutex_A);
        sched_yield();
        goto again;
    }
sched_yield()

- What you want for SCHED_DEADLINE!
- Tells the kernel the task is done with current period
- Used to relinquish the rest of the runtime budget
Donut Hole Puncher!
Deadline vs Period

- Can't have offset holes in our donuts
- Have a specific deadline to make within a period

runtime $\leq$ deadline $\leq$ period

$$U = \sum_{i=1}^{n} \frac{C_i}{D_i} = 1$$
Multi processors!

It's all fun and games until someone throws another processor into your eye
Multi processors! (Dhall's Effect)

- M CPUs
- M+1 tasks
- One task with runtime 999ms out of 1000ms
- M tasks of runtime of 10ms out of 999ms

\[
\frac{999}{1000} + M \left( \frac{10}{999} \right) = 0.999 + .01001 \quad M < M
\]

\[
M = 2; \quad \frac{999}{1000} + 2\left( \frac{10}{999} \right) = 0.999 + 2 \times 0.01001 = 1.01902 < 2
\]

- All start at the same time
- The M tasks have a shorted deadline
- All M tasks run on all CPUs for 10ms
- That one task now only has 990 ms left to run 999ms.
Multi processors!

- **EDF can not give you better than** $U = 1$
  - No matter how many processors you have
  - Full utilization should be $U = N$ CPUs

- **Two methods**
  - Partitioning (Bind each task to a CPU)
  - Global (let all tasks migrate wherever)
  - Neither give better than $U = 1$ guarantees
Multi processors!

• EDF partitioned

Can not always be used:
  • U_t1 = .6
  • U_t2 = .6
  • U_t3 = .5
  • The above would need special scheduling to work anyway

To figure out the best utilization is the bin packing problem
  • Sorry folks, it's NP complete
  • Don't even bother trying
Multi processors!

- Global Earliest Deadline First (gEDF)
- Can not guarantee deadlines of $U > 1$ for all cases
- But special cases can be satisfied for $U > 1$

\[ D_i = P_i \]

\[ U_{\text{max}} = \max\{C_i/P_i\} \]

\[
U = \sum_{i=1}^{n} \frac{C_i}{P_i} \leq M - (M - 1) \times U_{\text{max}}
\]
Multi processors!

- $M = 8$
- $U_{\text{max}} = 0.5$

\[
U = \sum_{i=1}^{n} \frac{C_i}{P_i} \leq M - (M - 1) \times U_{\text{max}}
\]

\[
U = \sum_{i=1}^{n} \frac{C_i}{P_i} \leq 8 - (7) \times 0.5 = 4.5
\]
Multi processors!

- $M = 2$
- $U_{\text{max}} = 999/1000$

\[
U = \sum_{i=1}^{n} \frac{C_i}{P_i} \leq M - (M - 1) \cdot U_{\text{max}}
\]

\[
U = \sum_{i=1}^{n} \frac{C_i}{P_i} \leq 2 - (1) \cdot 0.999 = 1.001
\]
The limits of SCHED_DEADLINE

- Runs on all CPUS (well sorta)
  - No limited sched affinity allowed
  - Global EDF is the default
  - Must account for sched migration overheads

- Can not have children (no forking)
  - Your SCHED_DEADLINE tasks have been fixed

- Calculating Worse Case Execution Time (WCET)
  - If you get it wrong, SCHED_DEADLINE may throttle your task before it finishes
Giving SCHED_DEADLINE Affinity

Setting task affinity on SCHED_DEADLINE is not allowed

But you can limit them by creating new sched domains
  CPU sets
  Implementing Partitioned EDF
Giving SCHED_DEADLINE Affinity

cd /sys/fs/cgroup/cpuset
Giving SCHED_DEADLINE Affinity

```bash
cd /sys/fs/cgroup/cpuset
mkdir my_set
```
Giving SCHED_DEADLINE Affinity

```
cd /sys/fs/cgroup/cpuset
mkdir my_set
mkdir other_set
```
Giving SCHED_DEADLINE Affinity

    cd /sys/fs/cgroup/cpuset
    mkdir my_set
    mkdir other_set
    echo 0-2 > other_set/cpuset.cpus
Giving SCHED_DEADLINE Affinity

cd /sys/fs/cgroup/cpuset
mkdir my_set
mkdir other_set
echo 0-2 > other_set/cpuset.cpus
echo 0 > other_set/cpuset.mems
Giving SCHED_DEADLINE Affinity

cd /sys/fs/cgroup/cpuset
mkdir my_set
mkdir other_set
echo 0-2 > other_set/cpuset.cpus
echo 0 > other_set/cpuset.mems
echo 1 > other_set/cpuset.sched_load_balance
Giving SCHED_DEADLINE Affinity

cd /sys/fs/cgroup/cpuset
mkdir my_set
mkdir other_set
echo 0-2 > other_set/cpuset.cpus
echo 0 > other_set/cpuset.mems
echo 1 > other_set/cpuset.sched_load_balance
echo 1 > other_set/cpuset.cpu_exclusive
Giving SCHED_DEADLINE Affinity

```
cd /sys/fs/cgroup/cpuset
mkdir my_set
mkdir other_set
echo 0-2 > other_set/cpuset.cpus
echo 0 > other_set/cpuset.mems
echo 1 > other_set/cpuset.sched_load_balance
echo 1 > other_set/cpuset.cpu_exclusive
echo 3 > my_set/cpuset.cpus
```
Giving SCHED_DEADLINE Affinity

cd /sys/fs/cgroup/cpuset
mkdir my_set
mkdir other_set
echo 0-2 > other_set/cpuset cpus
echo 0 > other_set/cpuset.mems
echo 1 > other_set/cpuset.sched_load_balance
echo 1 > other_set/cpuset.cpu_exclusive
echo 3 > my_set/cpuset cpus
echo 0 > my_set/cpuset.mems
Giving SCHED_DEADLINE Affinity

```bash
cd /sys/fs/cgroup/cpuset
mkdir my_set
mkdir other_set

echo 0-2 > other_set/cpuset.cpus
echo 0 > other_set/cpuset.mems
echo 1 > other_set/cpuset.sched_load_balance
echo 1 > other_set/cpuset.cpu_exclusive

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echo 0 > my_set/cpuset.mems
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echo 1 > other_set/cpuset.sched_load_balance
echo 1 > other_set/cpuset.cpu_exclusive
echo 3 > my_set/cpuset.cpus
echo 0 > my_set/cpuset.mems
echo 1 > my_set/cpuset.sched_load_balance
echo 1 > my_set/cpuset.cpu_exclusive
```
Giving SCHED_DEADLINE Affinity

cd /sys/fs/cgroup/cpuset
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echo 0-2 > other_set/cpuset.cpus
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echo 1 > other_set/cpuset.cpu_exclusive
echo 3 > my_set/cpuset.cpus
echo 0 > my_set/cpuset.mems
echo 1 > my_set/cpuset.sched_load_balance
echo 1 > my_set/cpuset.cpu_exclusive
echo 0 > cpuset.sched_load_balance
Giving SCHED_DEADLINE Affinity

cat tasks | while read task; do
echo $task > other_set/tasks
done

echo $sched_deadline_task > my_set/tasks
Calculating WCET

- Today's hardware is extremely unpredictable
- Worse Case Execution Time is impossible to know
- Allocate too much bandwidth instead
- Need something between RMS and CBS
GRUB (not the boot loader)

- Greedy Reclaim of Unused Bandwidth
- Allows for SCHED_DEADLINE tasks to use up the unused utilization of the CPU (or part of it)
- Allows for tasks to handle WCET of a bit more than calculated.
- Just went into mainline (v4.13)
GRUB with SCHED_DEADLINE in Linux

Constant Bandwidth Server (CBS)

\[
\frac{\text{remaining runtime}}{\text{scheduling deadline} - \text{current time}} > \frac{\text{runtime}}{\text{period}}
\]

scheduling deadline = current time + deadline
remaining runtime = runtime
GRUB with SCHED_DEADLINE in Linux

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Active Utilization

\[
U^{\text{act}} = U^{\text{act}} + \frac{C_i}{T_i}
\]
GRUB with SCHED_DEADLINE in Linux

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Active Utilization

\[
U^{\text{act}} = U^{\text{act}} + \frac{C_i}{T_i}
\]

\[
U^{\text{act}} = U^{\text{act}} - \frac{C_i}{T_i}
\]
GRUB with SCHED_DEADLINE in Linux

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Active Utilization

\[
U^{act} = U^{act} + \frac{C_i}{T_i}
\]

\[
U^{act} = U^{act} - \frac{C_i}{T_i}
\]

\[
\frac{q_i}{d_i - t} > \frac{C_i}{P_i}
\]
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U^{\text{act}} = U^{\text{act}} - \frac{C_i}{T_i}
\]

\[
\frac{q_i}{d_i - t} > \frac{C_i}{P_i}
\]

\[
t > d_i - q_i\left(\frac{P_i}{C_i}\right)
\]
GRUB with SCHED_DEADLINE in Linux

Constant Bandwidth Server (CBS)

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\]

scheduling deadline = current time + deadline
remaining runtime = runtime

Active Utilization

\[
d_i = t + P_i
\]

\[
U^{\text{act}} = U^{\text{act}} + \frac{C_i}{T_i}
\]

\[
U^{\text{act}} = U^{\text{act}} - \frac{C_i}{T_i}
\]

\[
\frac{q_i}{d_i - t} > \frac{C_i}{P_i}
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\[
t > d_i - q_i\left(\frac{P_i}{C_i}\right)
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Active Utilization

\[
d_i = t + P_i
\]

\[
q_i = C_i
\]

\[
U^{act} = U^{act} + \frac{C_i}{T_i}
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U^{act} = U^{act} - \frac{C_i}{T_i}
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\frac{q_i}{d_i - t} > \frac{C_i}{P_i}
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Active Utilization

\[
d_i = t + P_i
\]
\[
q_i = C_i
\]
\[
q_i = q_i - \delta
\]
\[
U^{\text{act}} = U^{\text{act}} + \frac{C_i}{T_i}
\]
\[
U^{\text{act}} = U^{\text{act}} - \frac{C_i}{T_i}
\]
\[
\frac{q_i}{d_i - t} > \frac{C_i}{P_i}
\]
\[
t > d_i - q_i \left( \frac{P_i}{C_i} \right)
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GRUB with SCHED_DEADLINE in Linux

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\]

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Active Utilization

\[
d_i = t + P_i
\]
\[
q_i = C_i
\]
\[
q_i = q_i - \delta
\]
\[
dq_i = -dt
\]

\[
U^{\text{act}} = U^{\text{act}} + \frac{C_i}{T_i}
\]

\[
U^{\text{act}} = U^{\text{act}} - \frac{C_i}{T_i}
\]

\[
q_i > \frac{C_i}{d_i - t} > \frac{P_i}{C_i}
\]

\[
t > d_i - q_i\left(\frac{P_i}{C_i}\right)
\]
GRUB with SCHED_DEADLINE in Linux

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d_i = t + P_i
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q_i = C_i
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q_i = q_i - \delta
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\[
dq_i = -dt
\]
\[
U^{act} = U^{act} + \frac{C_i}{T_i}
\]
\[
U^{act} = U^{act} - \frac{C_i}{T_i}
\]
\[
t = d_i - q_i \left( \frac{P_i}{C_i} \right)
\]
GRUB with SCHED_DEADLINE in Linux

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scheduling deadline = current time + deadline
remaining runtime = runtime

Active Utilization

\[ d_i = t + P_i \]
\[ q_i = C_i \]
\[ q_i = q_i - \delta \]
\[ dq_i = -\, dt \]

\[ U^{act} = U^{act} + \frac{C_i}{T_i} \]
\[ U^{act} = U^{act} - \frac{C_i}{T_i} \]
\[ dq_i = -U^{act} \, dt \]

\[ t > d_i - q_i \left( \frac{P_i}{C_i} \right) \]
\[ t = d_i - q_i \left( \frac{P_i}{C_i} \right) \]
GRUB with SCHED_DEADLINE in Linux

Constant Bandwidth Server (CBS)

\[
\frac{\text{remaining runtime}}{\text{scheduling deadline} - \text{current time}} > \frac{\text{runtime}}{\text{period}}
\]

scheduling deadline = current time + deadline
remaining runtime = runtime

Active Utilization

\[
d_i = t + P_i \\
q_i = C_i \\
q_i = q_i - \delta \\
dq_i = -dt
\]

\[
U^{act} = U^{act} + \frac{C_i}{T_i}
\]

\[
U^{act} = U^{act} - \frac{C_i}{T_i}
\]

\[
t = d_i - q_i \left( \frac{P_i}{C_i} \right)
\]

\[
\frac{q_i}{d_i - t} > \frac{C_i}{P_i}
\]

\[
t > d_i - q_i \left( \frac{P_i}{C_i} \right)
\]

\[
dq_i = -U^{act} dt
\]

\[
q_i = q_i - \delta U^{act}
\]
Links

Documentation/scheduler/sched_deadline.txt
http://disi.unitn.it/~abeni/reclaiming/rtlws14-grub.pdf
http://www.evidence.eu.com/sched_deadline.html
https://cs.unc.edu/~anderson/papers/rtj06a.pdf
Thank You
Steven Rostedt