Using SCHED_DEADLINE

Controlling CPU Bandwidth

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What is SCHED_DEADLINE?

- A new scheduling class
  - 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

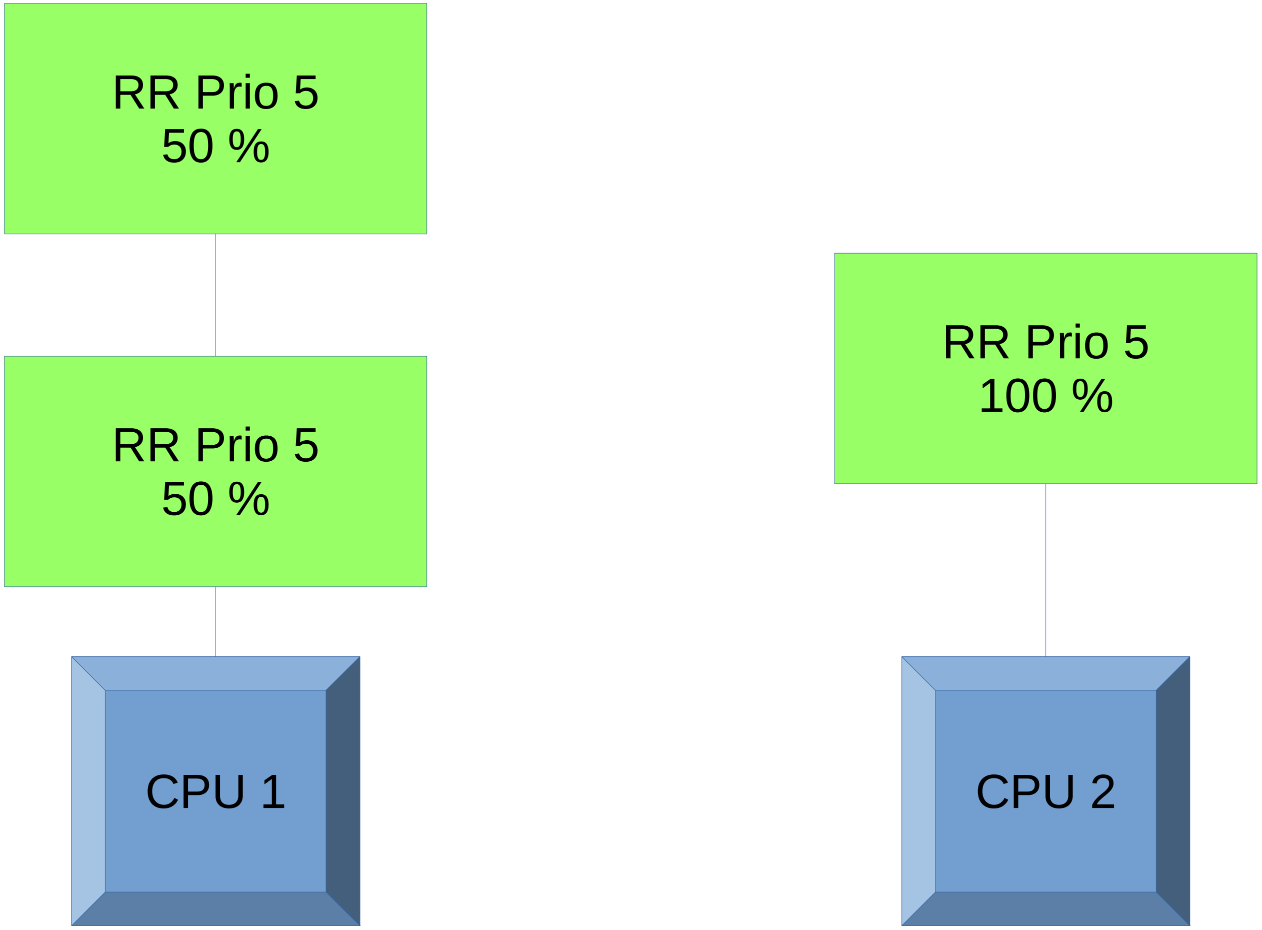
SCHED_FIFO

- 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

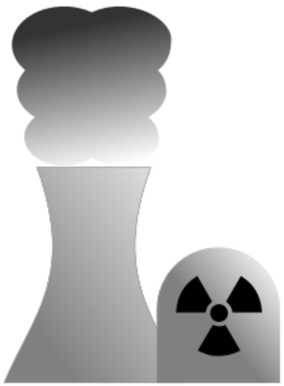
SCHED_RR (Round Robin)

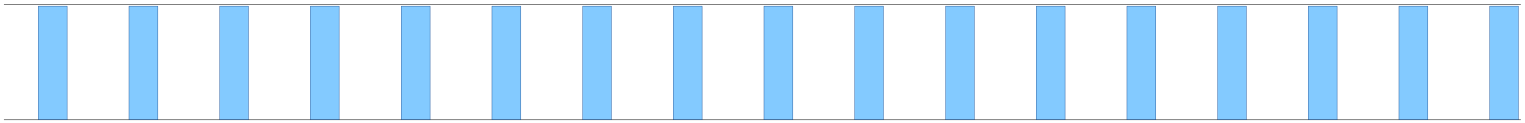


Priorities

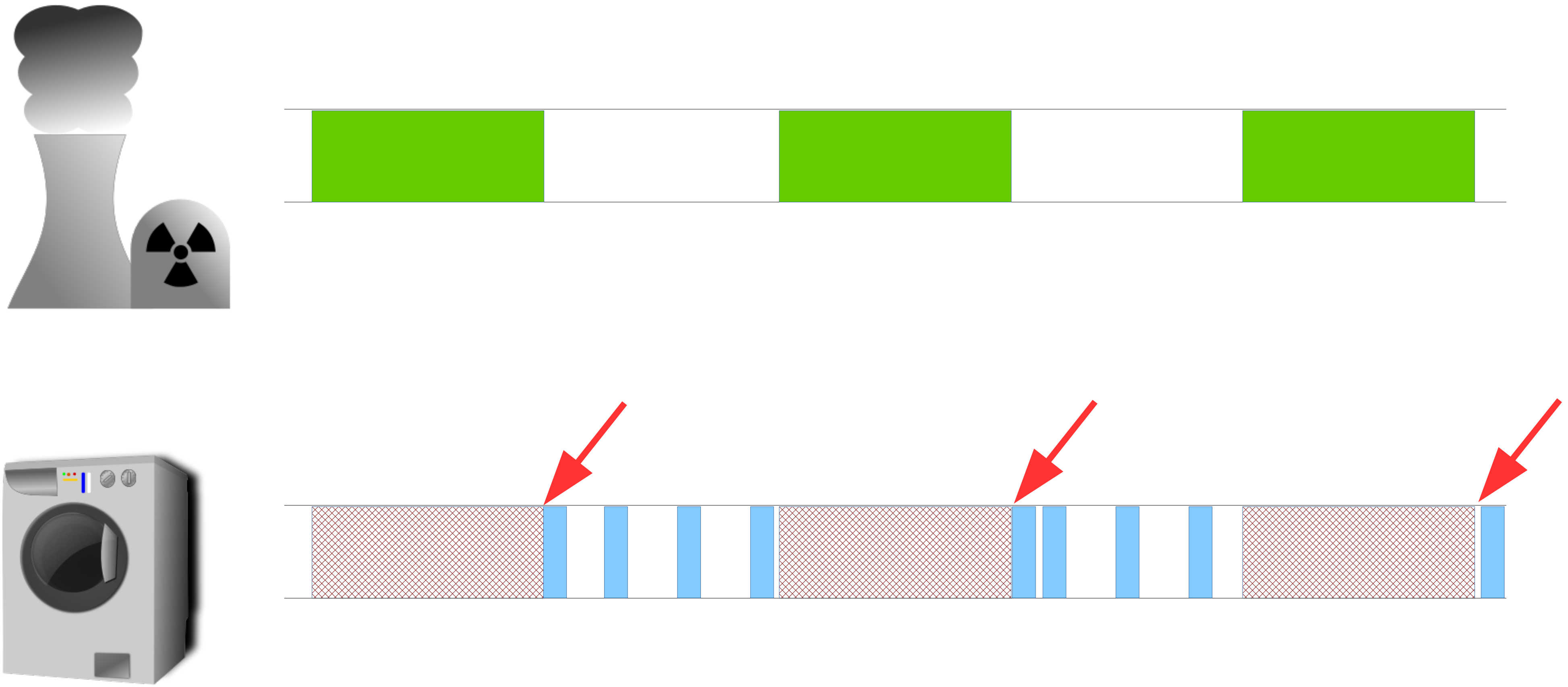
- You have two programs running on the same CPU
  - One runs a nuclear power plant
    - Requires 1/2 second out of every second of the CPU
  - The other runs a washing machine
    - Requires 50 millisecond out of every 200 milliseconds
  - Which one gets the higher priority?

Priorities





Priorities Nuke > Washing Machine



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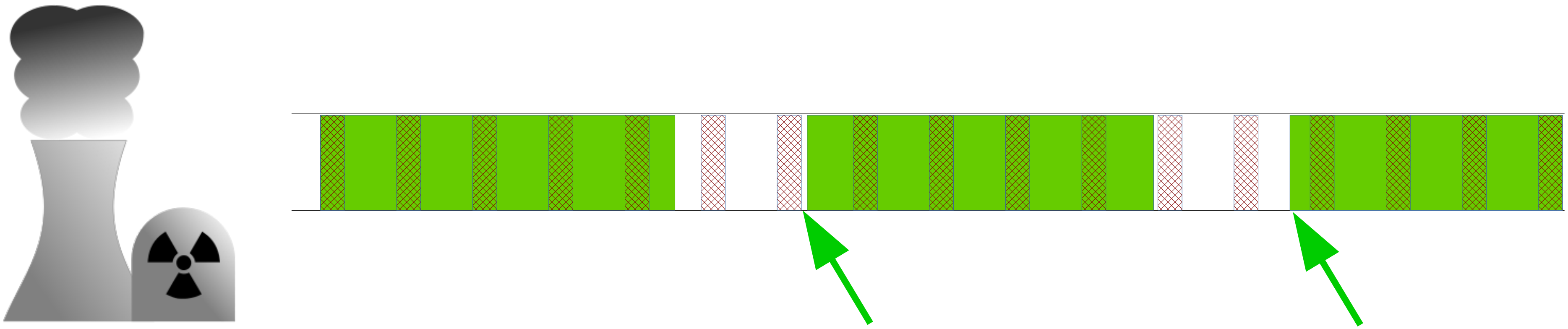

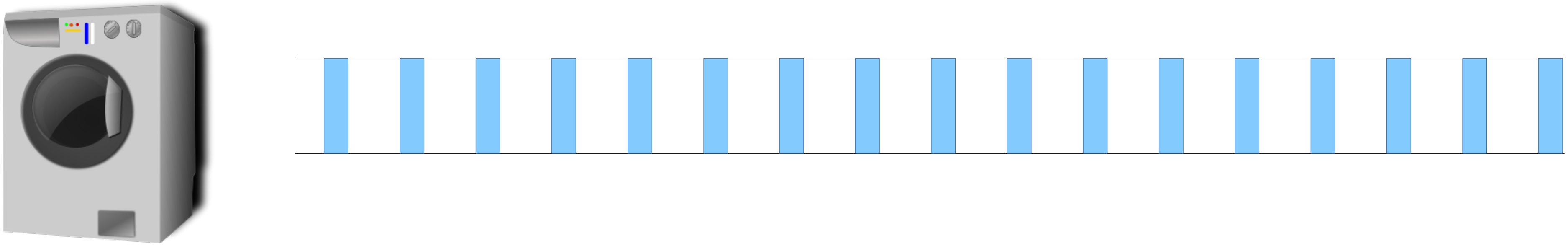

Rate Monotonic Scheduling (RMS)

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 = 500ms T=1000ms

Dishwasher: C = 300ms T = 900ms

Washing Machine: C = 100ms T = 800ms

$$U = \frac{500}{1000} + \frac{300}{900} + \frac{100}{800} = .958333$$

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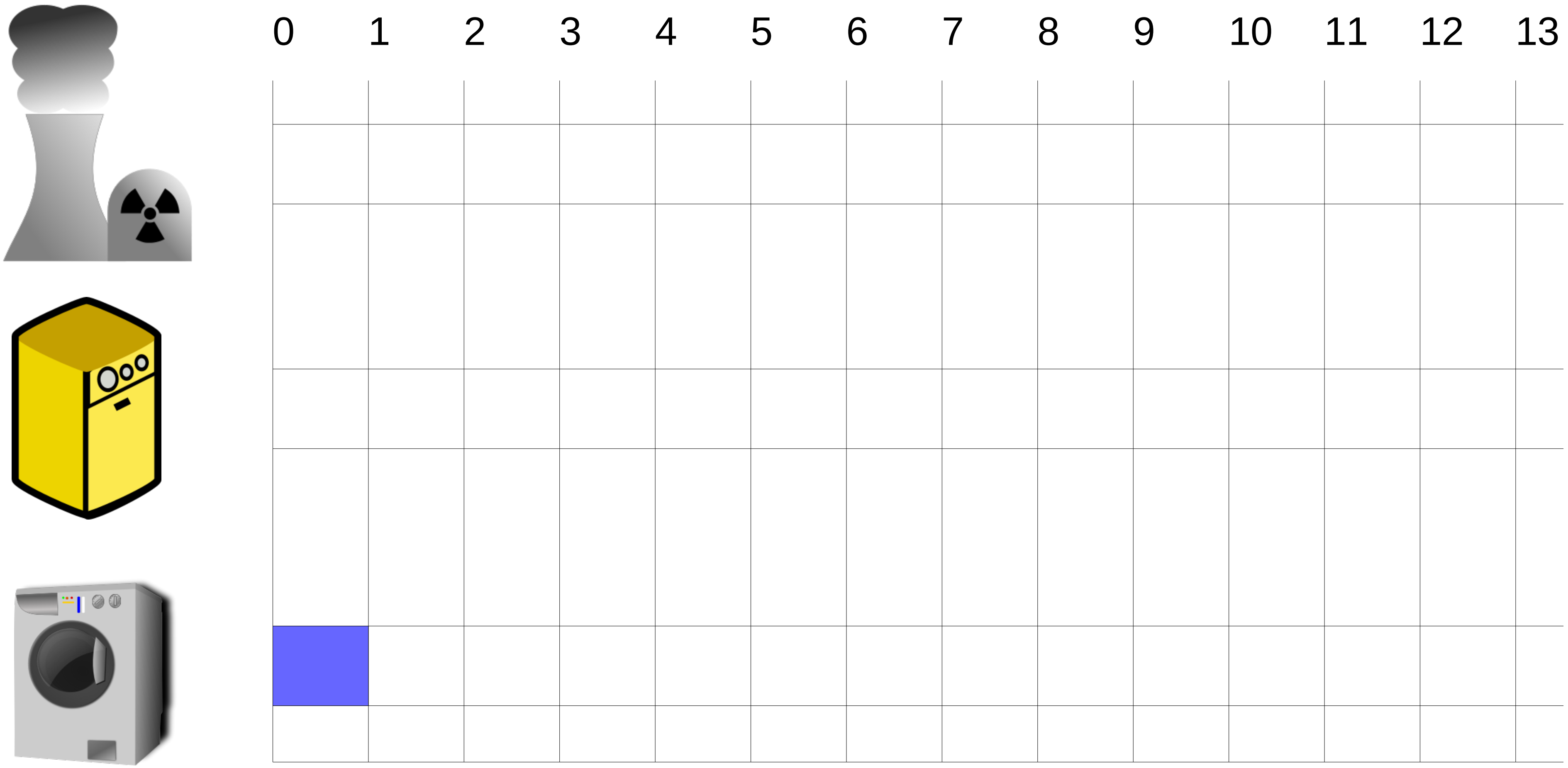

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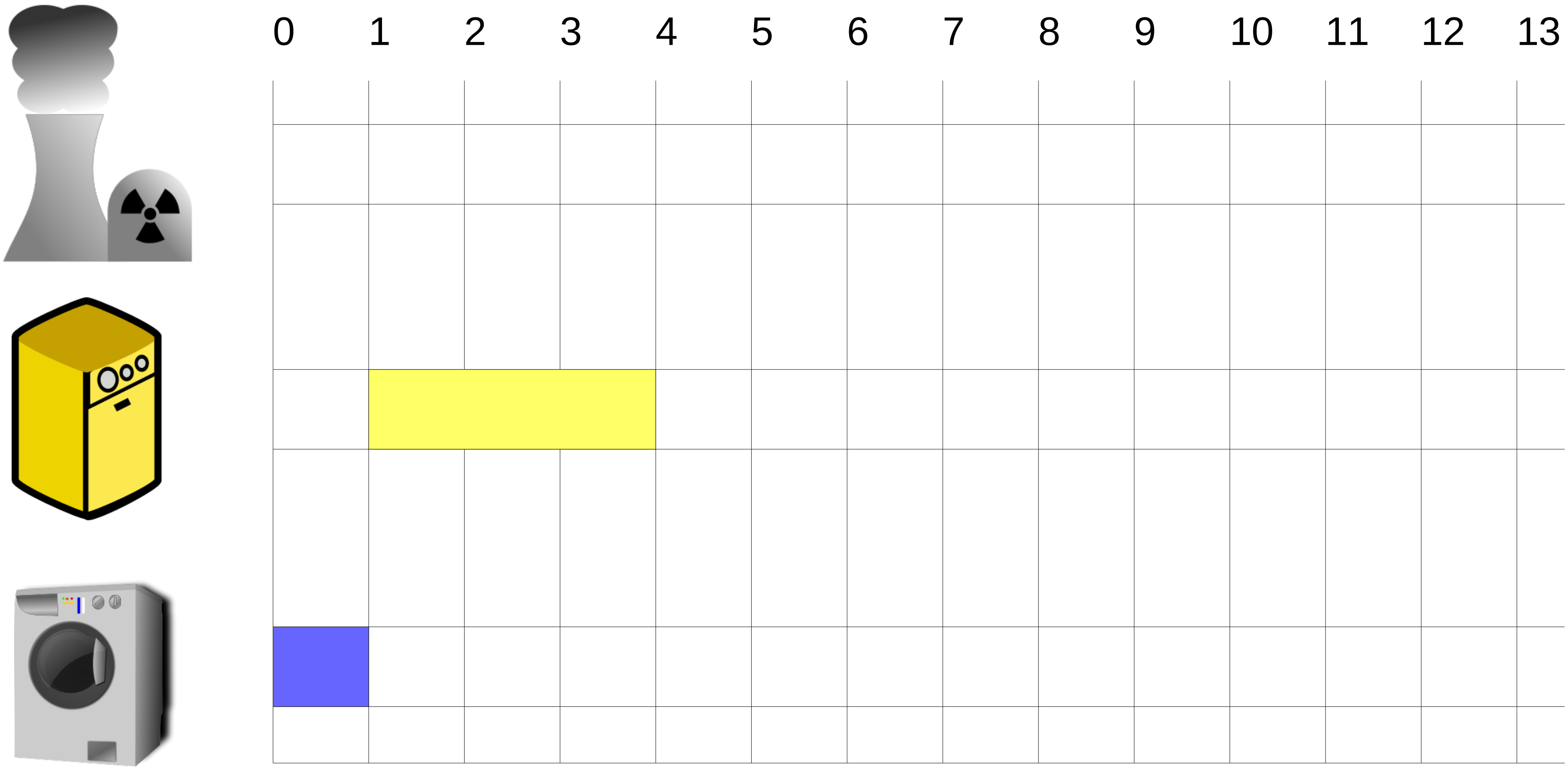

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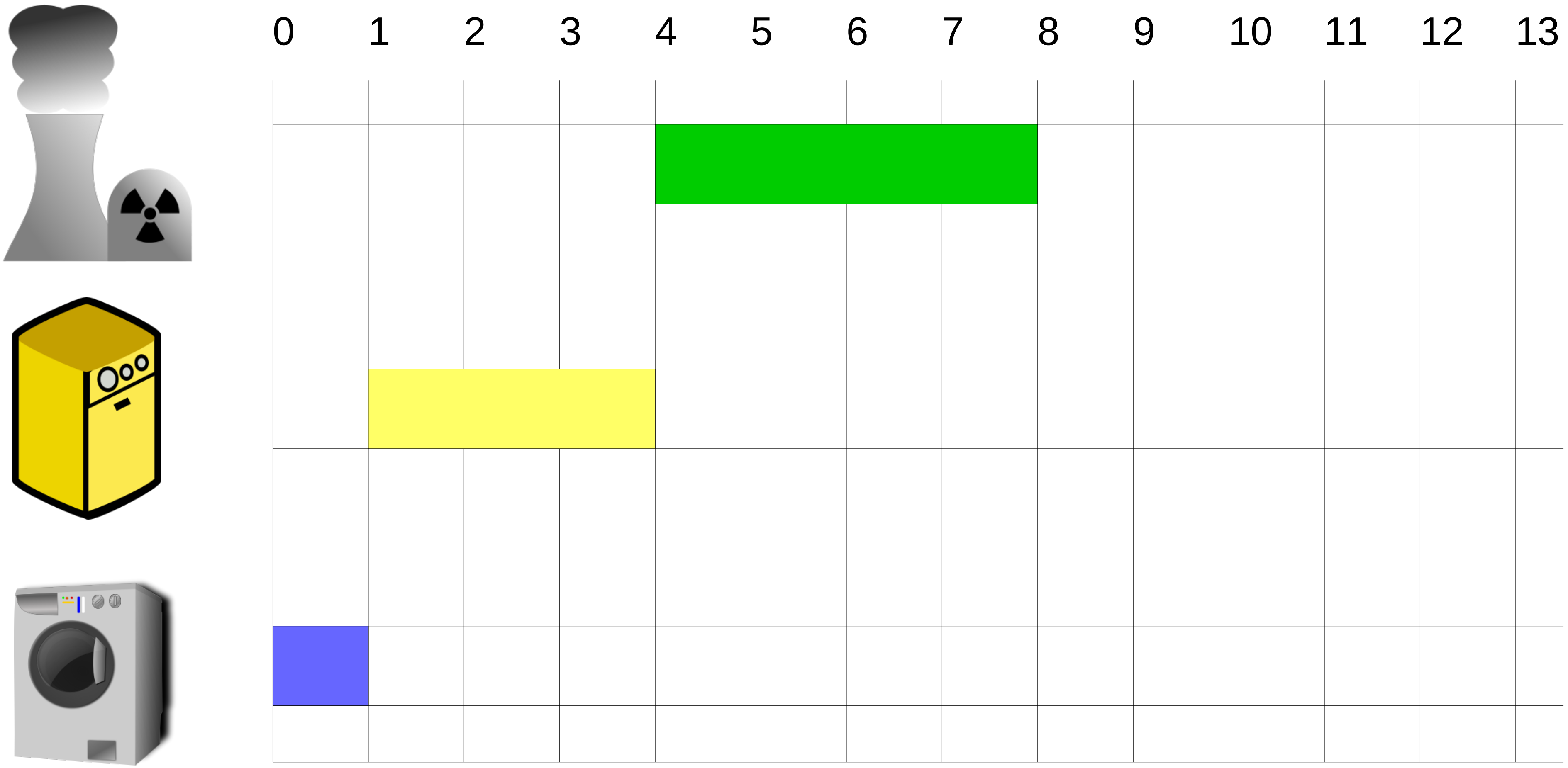

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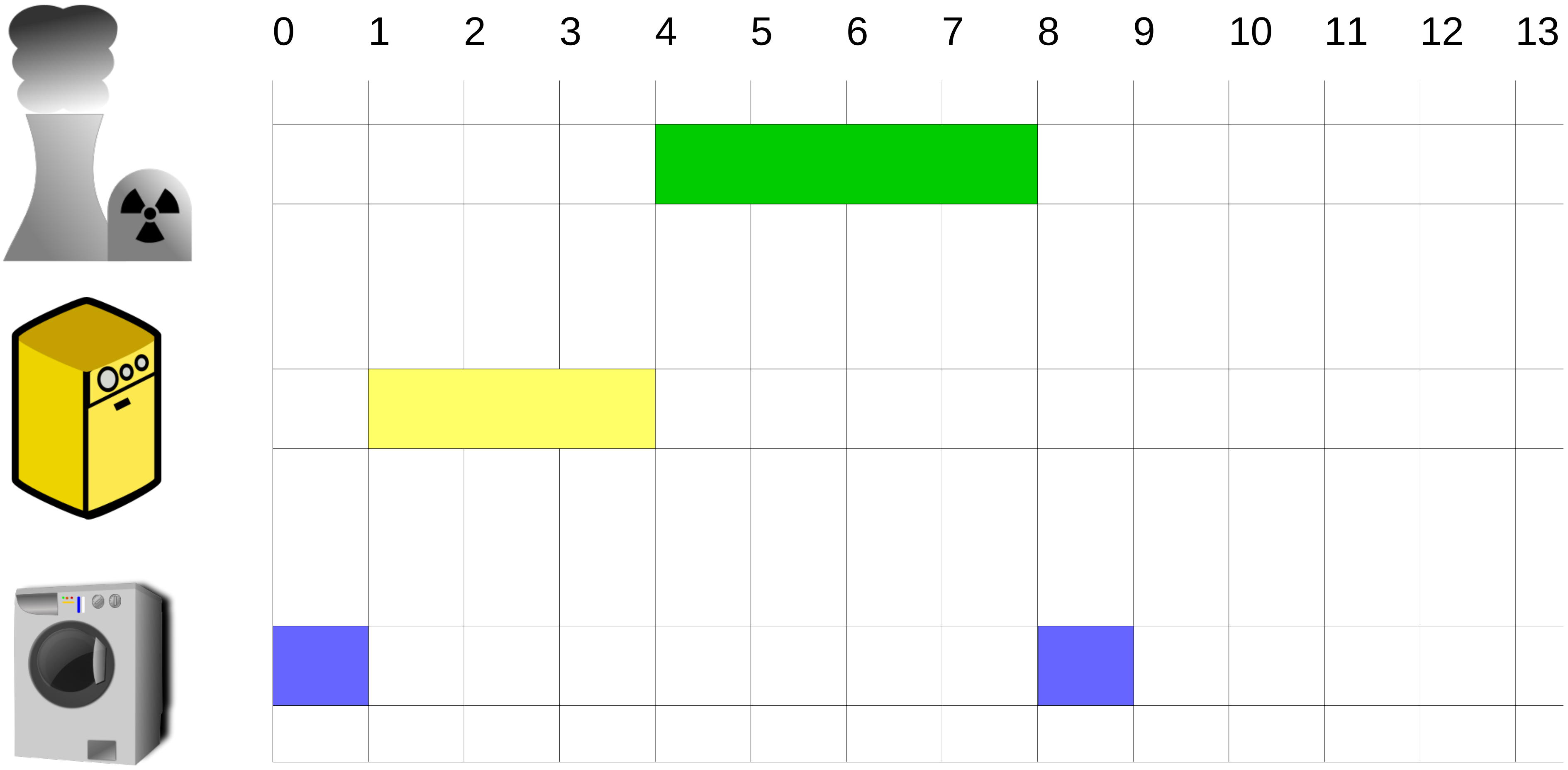

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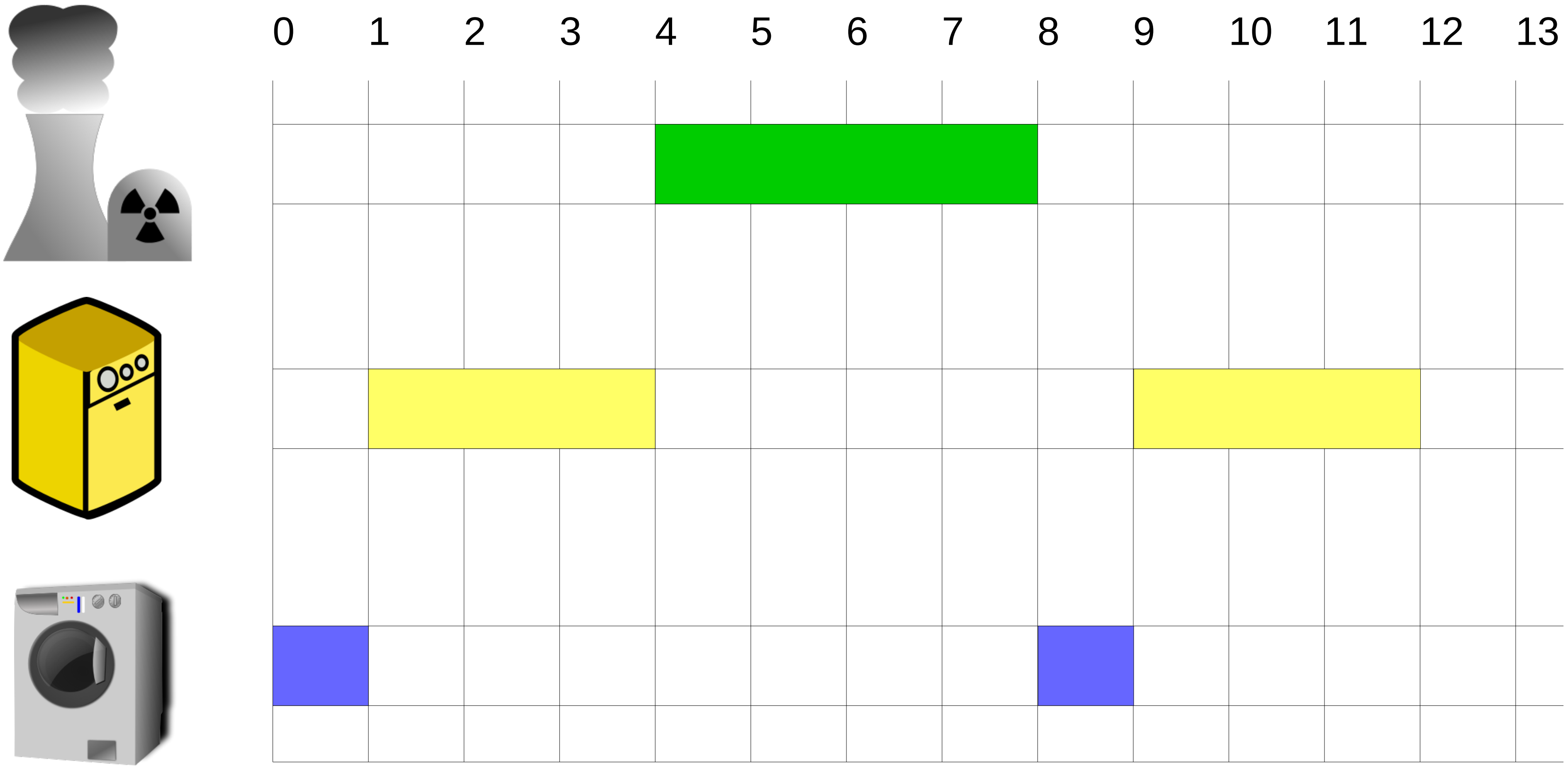

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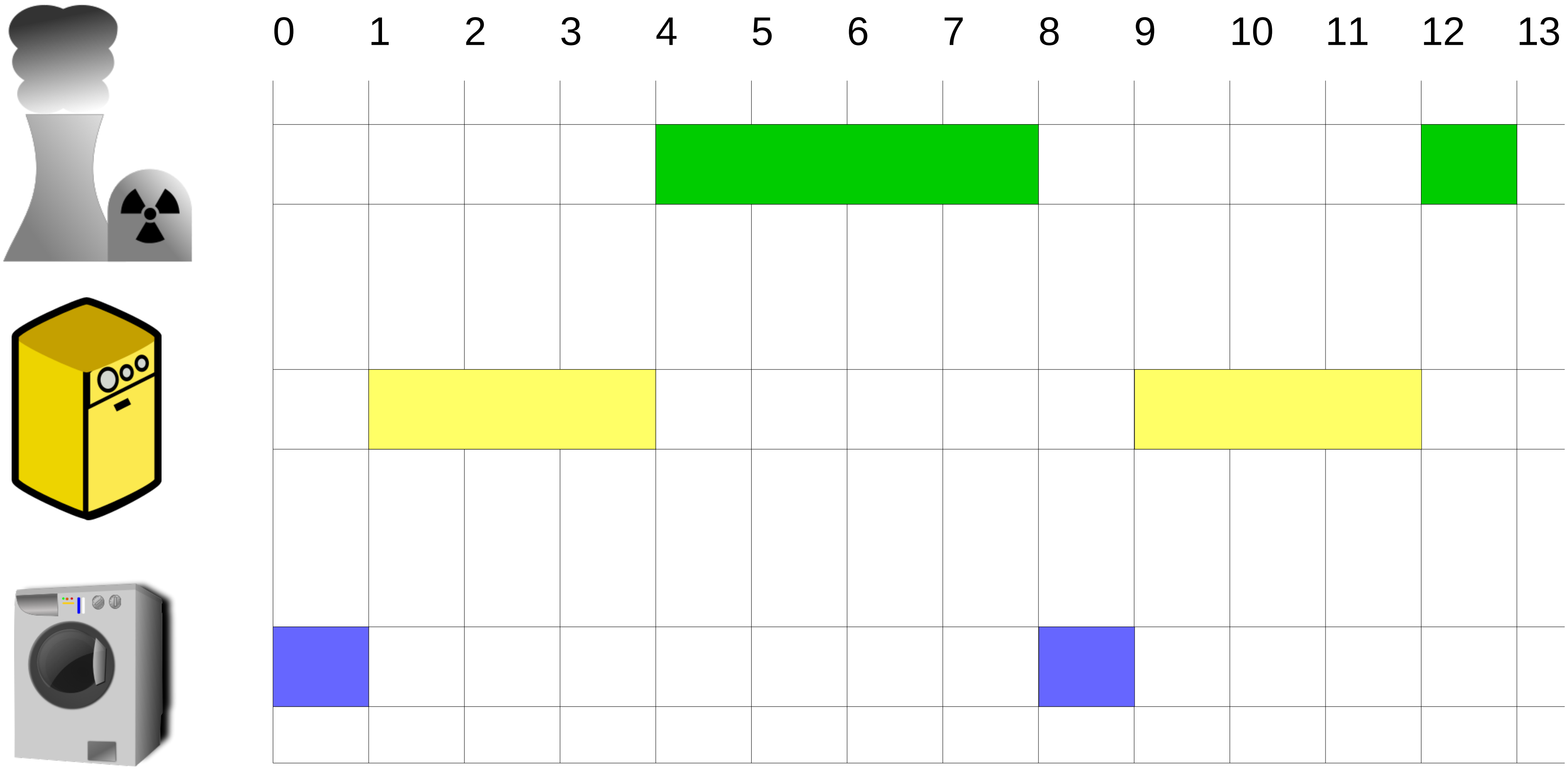

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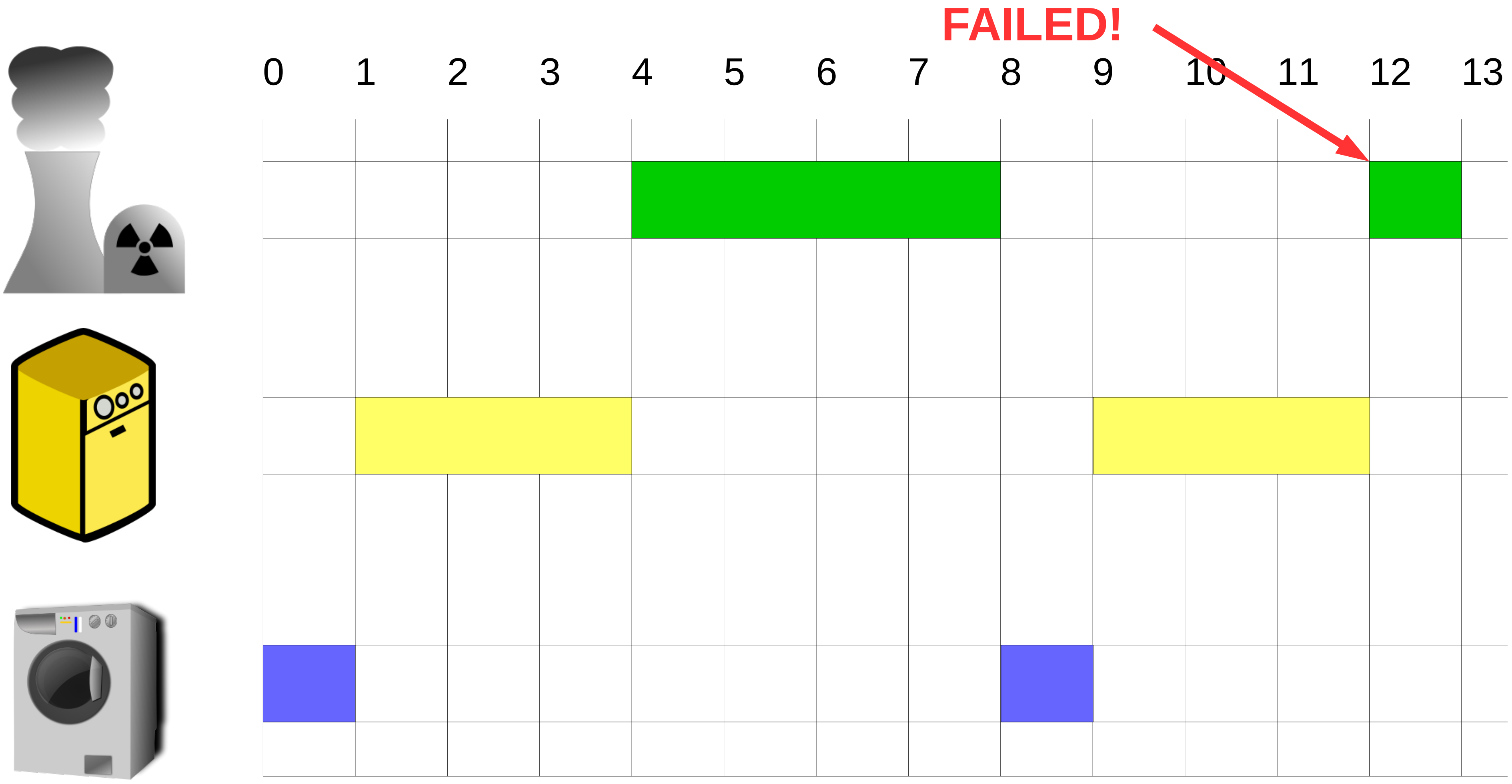

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$$U = \sum_{i=1}^{n} \frac{C_i}{T_i} \leq n\left(\sqrt[n]{2} - 1\right)$$

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$$U \leq n\left(\sqrt[n]{2} - 1\right) = 3\left(\sqrt[3]{2} - 1\right) = 0.77976$$

Rate Monotonic Scheduling (RMS)

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

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

SCHED_DEADLINE

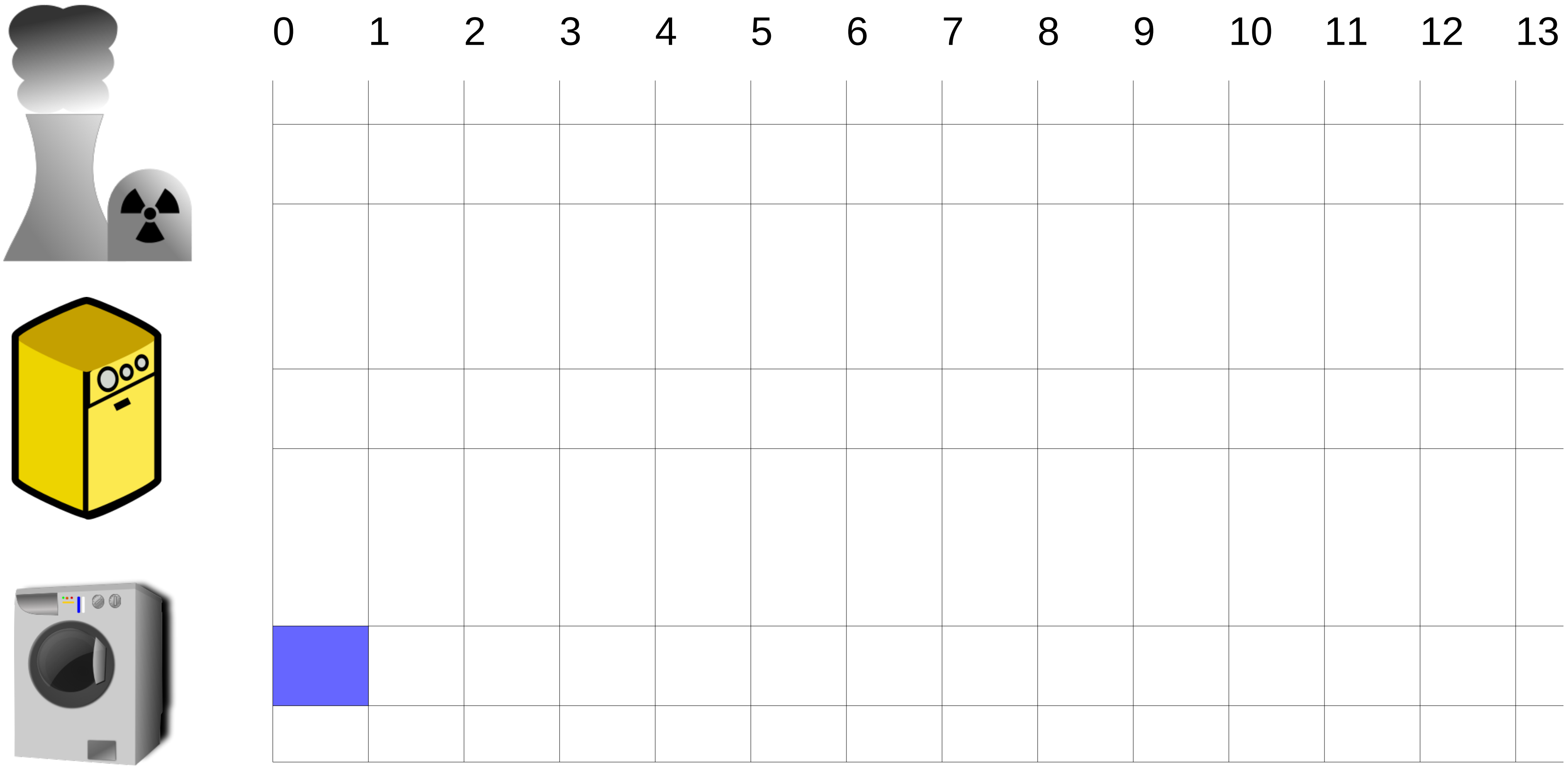
Utilizes Earliest Deadline First (EDF)

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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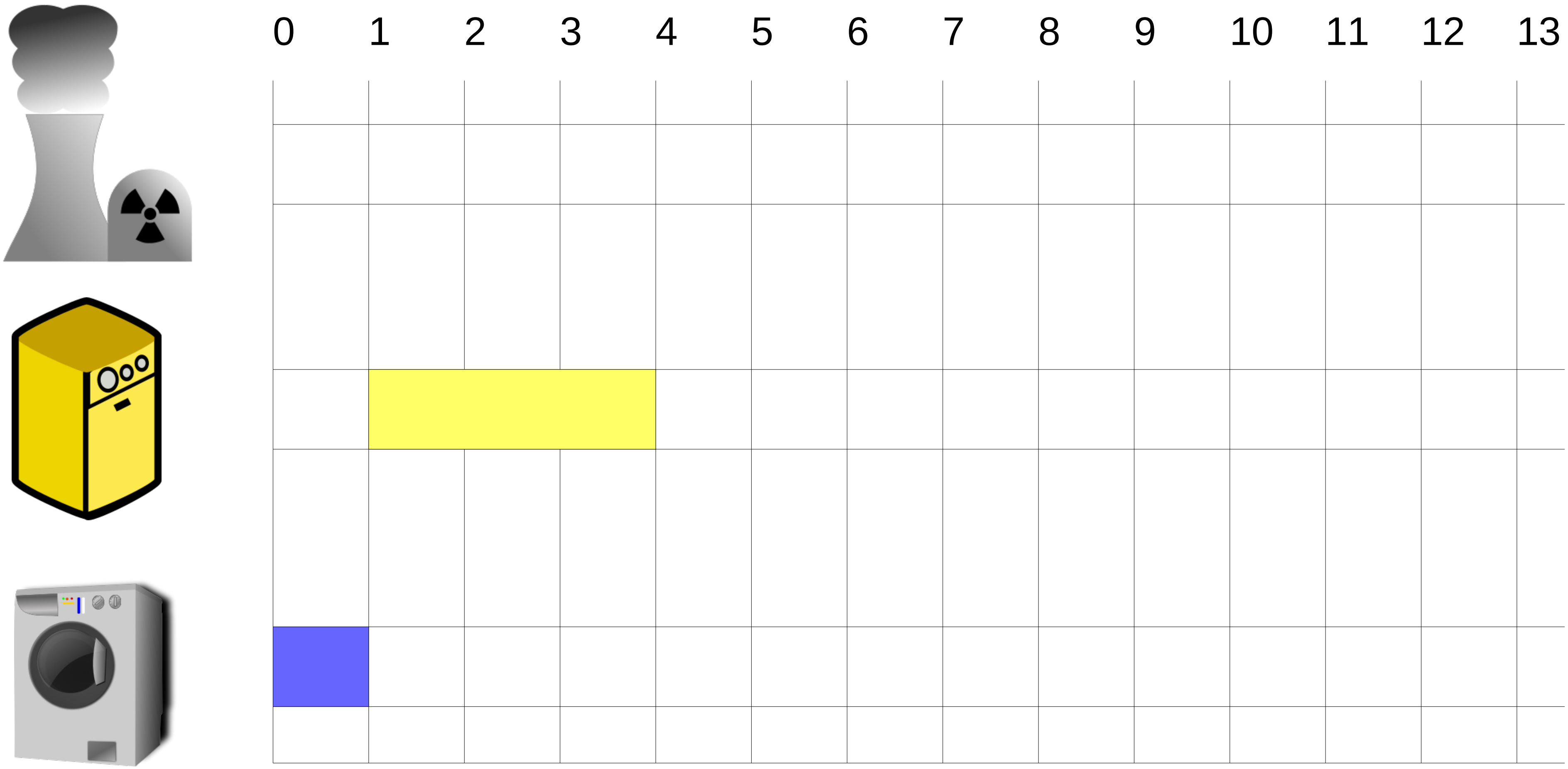

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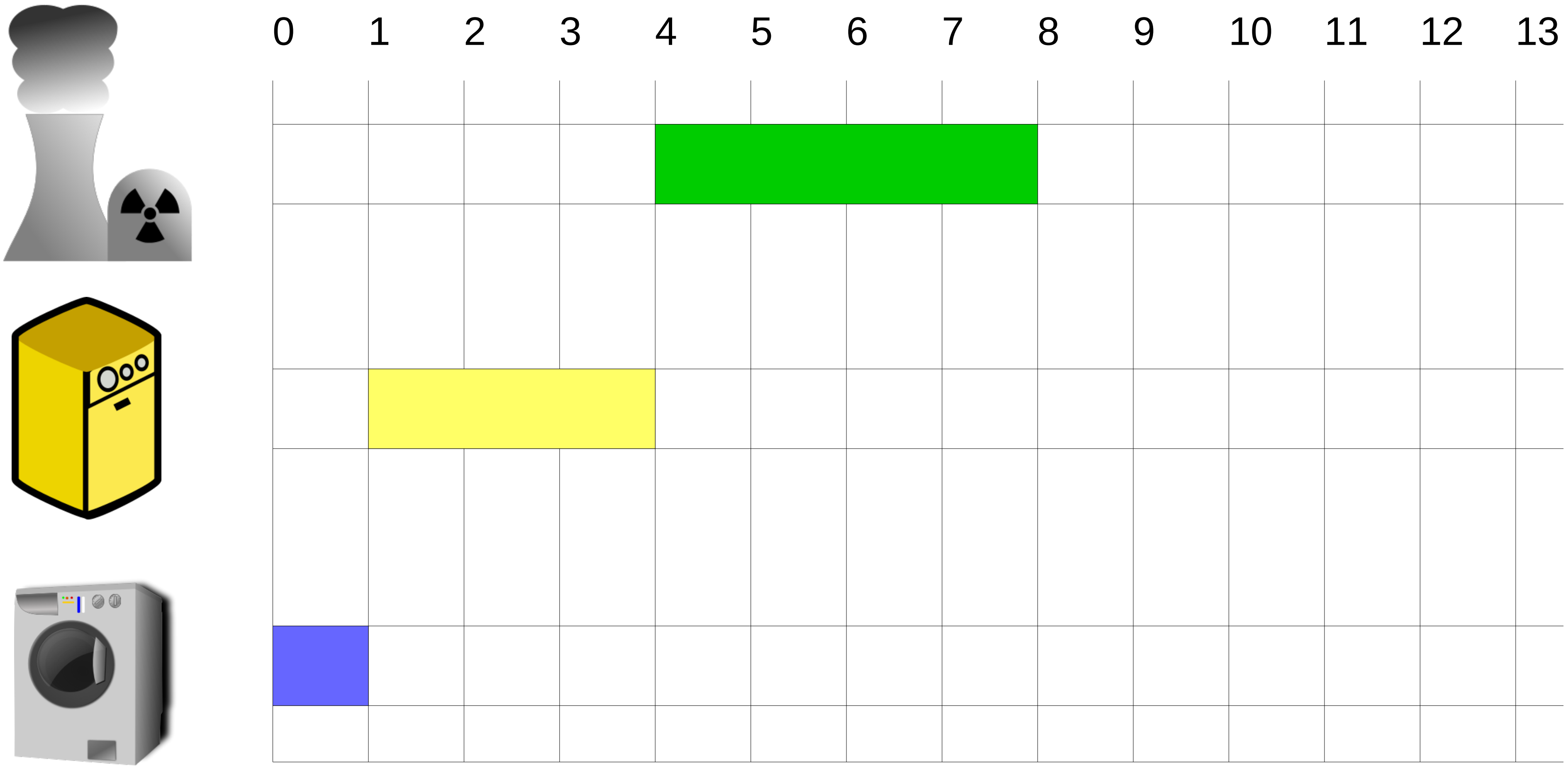

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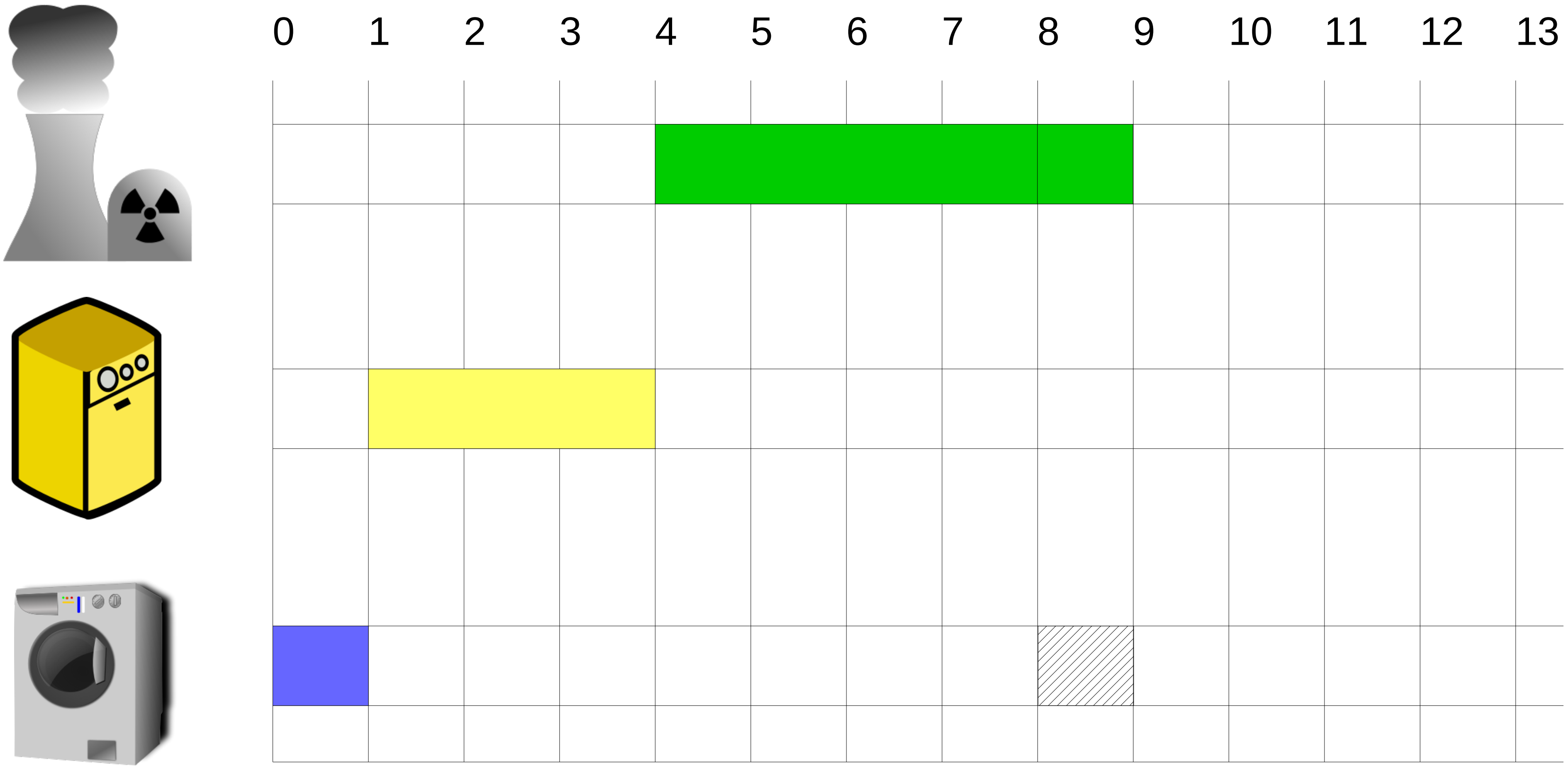

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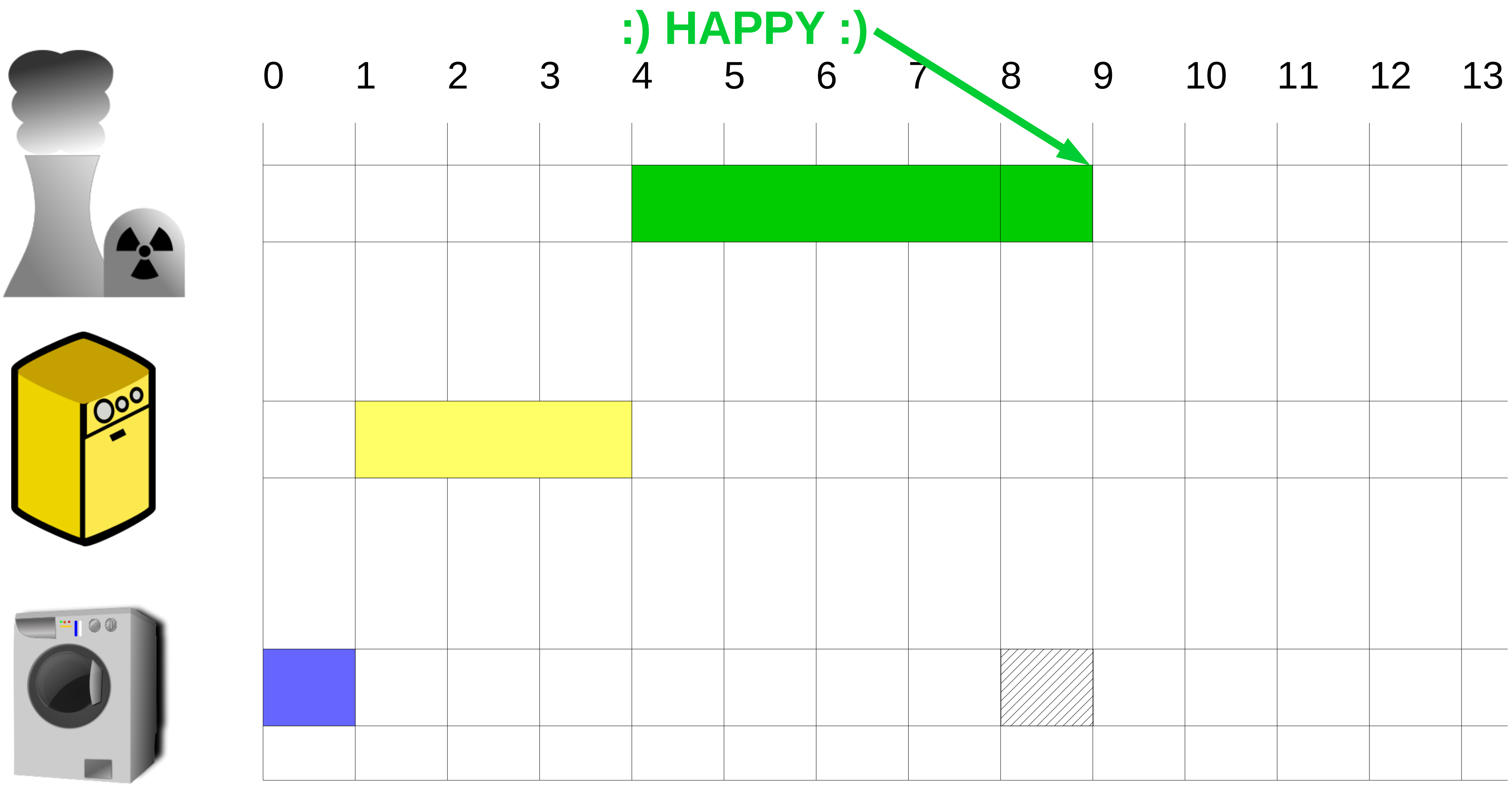

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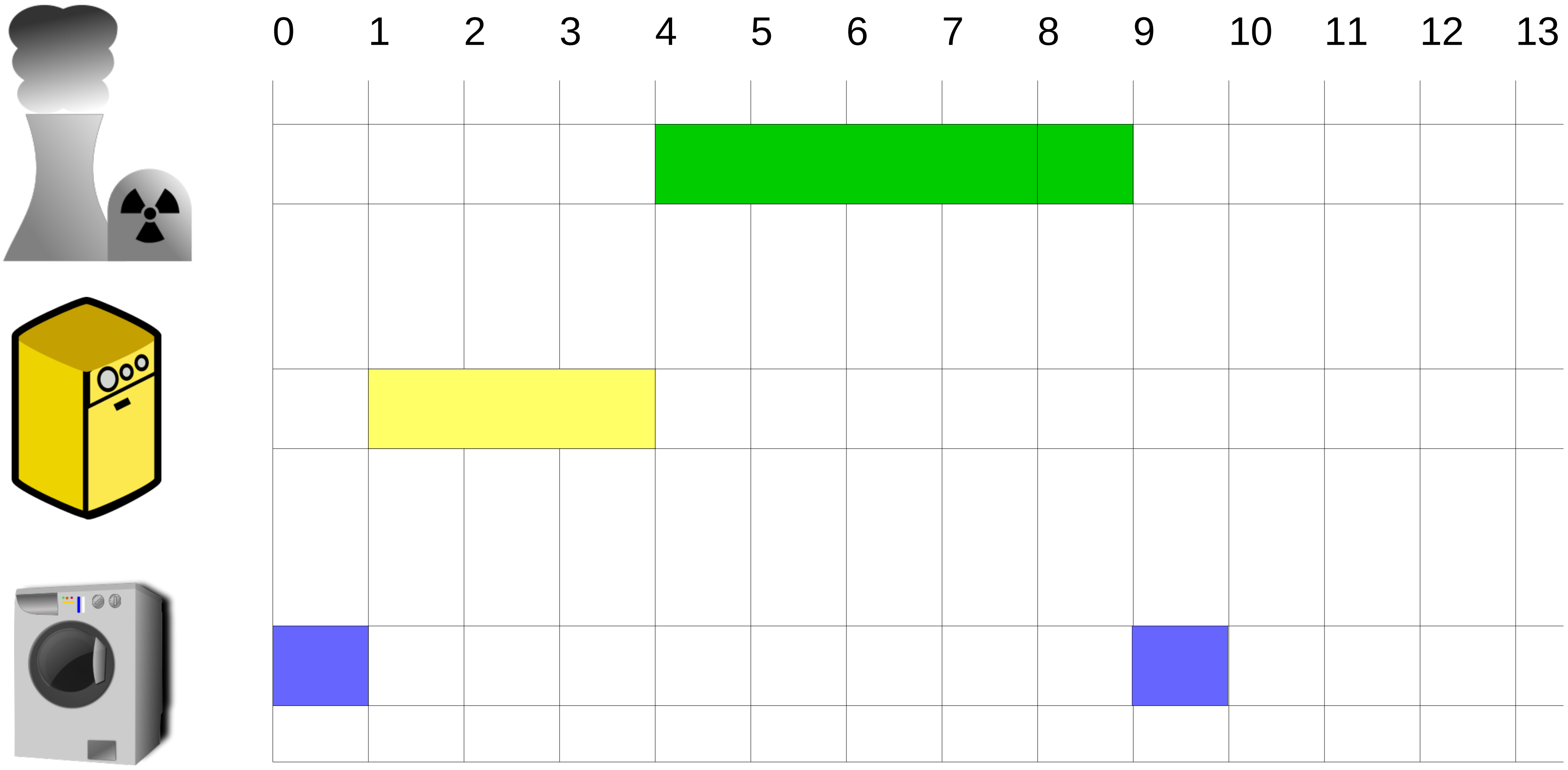

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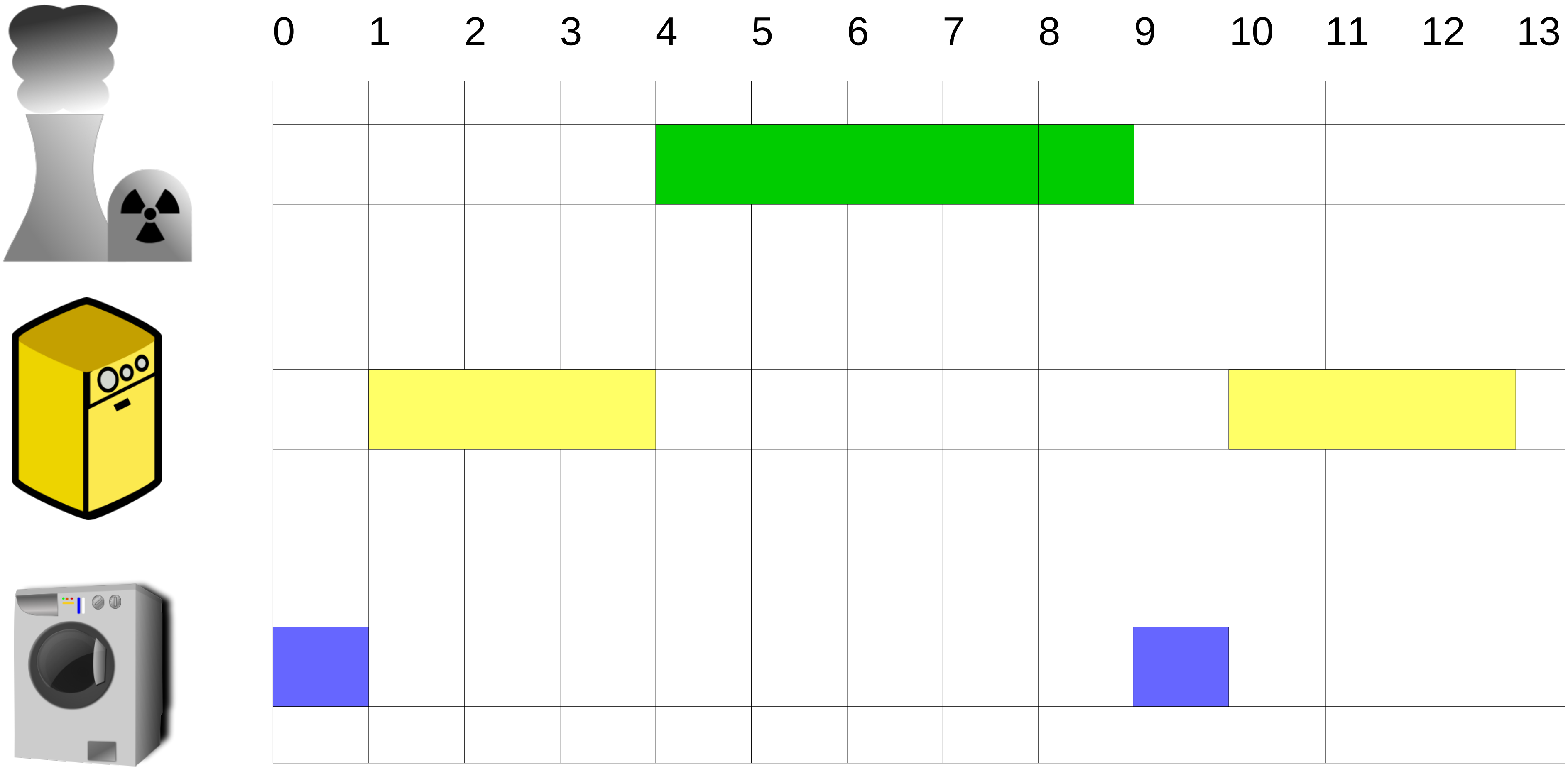


Implementing SCHED_DEADLINE

Two new syscalls

```
sched_getattr(pid_t pid, struct sched_attr *attr,
              unsigned int size, unsigned int flags)

sched_setattr(pid_t pid, struct sched_attr *attr,
              unsigned int flags)
```

Implementing SCHED_DEADLINE

```
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) */
    /* Remaining fields are for SCHED_DEADLINE */
    u64 sched_runtime;
    u64 sched_deadline;
    u64 sched_period;
};
```

Implementing SCHED_DEADLINE

```
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;
    }
```

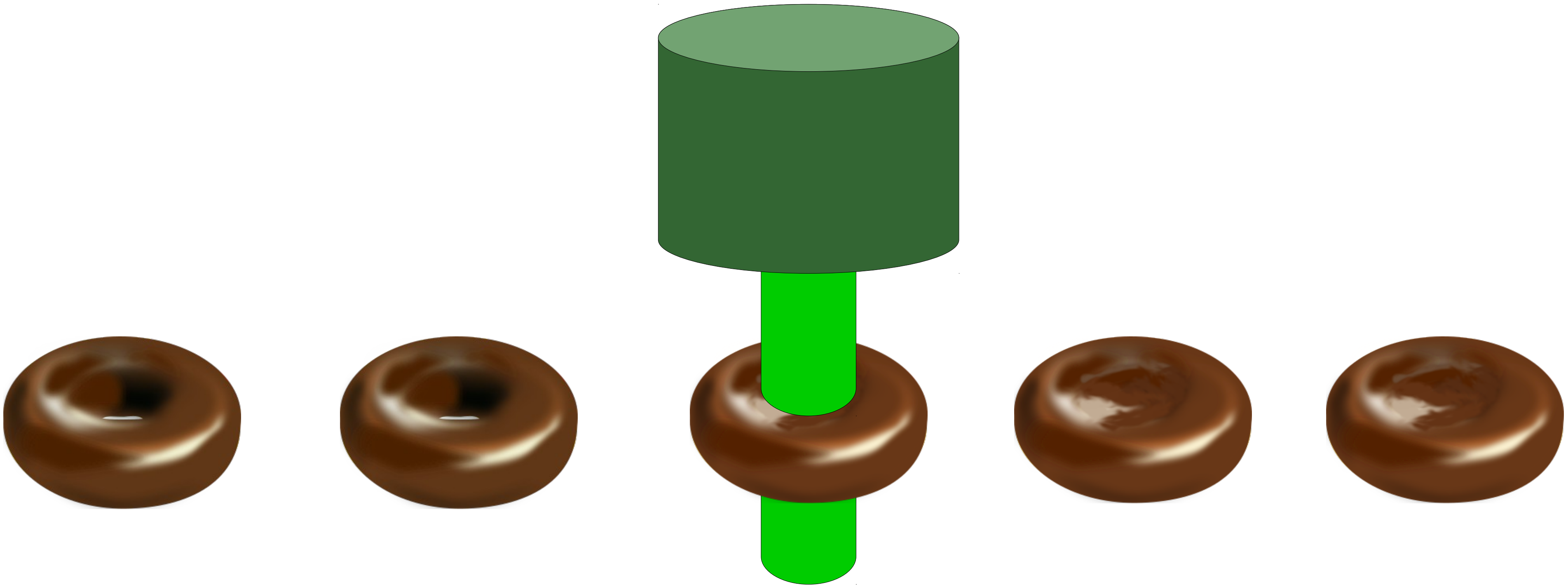
sched_yield()

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 <= deadline <= 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

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
- 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_max = max{C_i/P_i}

$$U = \sum_{i=1}^{n} \frac{C_i}{P_i} \leq M - (M-1) * U_{max}$$

Multi processors!

M = 8

U_max = 0.5

$$U = \sum_{i=1}^{n} \frac{C_i}{P_i} \leq M - (M-1) * U_{max}$$

$$U = \sum_{i=1}^{n} \frac{C_i}{P_i} \leq 8 - (7) * .5 = 4.5$$

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
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
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.

Not mainline yet, but we are working on that

Links

Documentation/scheduler/sched_deadline.txt

http://disi.unitn.it/~abeni/reclaiming/rtlws14-grub.pdf

http://www.evidence.eu.com/sched_deadline.html

http://www.atc.uniovi.es/rsa/starts/documents/Lopez_2004_rts.pdf

https://cs.unc.edu/~anderson/papers/rtj06a.pdf

Questions?