CIS 721 - Real-Time Systems
Lecture 10: Arbitrary Deadlines

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Outline

- **Priority-Driven Scheduling**
  - **Periodic Tasks (Ch. 6)**
    - **Arbitrary Start Times**
      - **Leung's Feasibility Test**
      - **Audsley's Feasibility Test**
    - **Arbitrary Deadlines**

Arbitrary Deadlines

- J.P. Lehoczky, "Fixed Priority Scheduling of Periodic Task Sets with Arbitrary Deadlines", In Proceedings of IEEE Real-Time Systems Symposium, pp. 201-209, December, 1990.
- K. Tindell, A. Burns, and A.J. Wellings, "An extensible approach for analysing fixed priority hard real-time tasks", Real-Time Systems, 6 (2), pp. 133-151, 1994.

Rate Monotonic Assignment?

- **Q:** What happens if task deadlines are allowed to be greater than their periods?
- **A:** Rate Monotonic and Deadline Monotonic Priority Assignments may no longer be optimal.

Terms and Concepts

- A **task set** $\Gamma = \{\boldsymbol{\tau}_1, \boldsymbol{\tau}_2, \ldots, \boldsymbol{\tau}_n\}$ is a collection of related tasks.
- Each **periodic task** τ_i is characterized by:
  - an **execution time** or **run-time** (C_i),
  - a **period** (T_i),
  - a **(relative) deadline** (D_i), and
  - a **phase** or **offset** (φ_i or O_i).

Release Time

- The **release time** (or **arrival time**) of a job is the time at which the job becomes available for execution (r_i).
- The release time of the j^{th} instant (job) of task τ_i is given by $r_i = O_i + (j-1)\, T_i$.
- **Assumption:** $O_i = 0$ for all i; thus, a critical instant occurs at time 0.

Level-i Busy Period

- A **level-i busy period** is a time interval [a, b] in which tasks of priority i or higher are processed, but no tasks of level-i are processed in $(a - \varepsilon, a)$ or $(b, b + \varepsilon)$ for some $\varepsilon > 0$.

Deadline Monotonic Scheduling

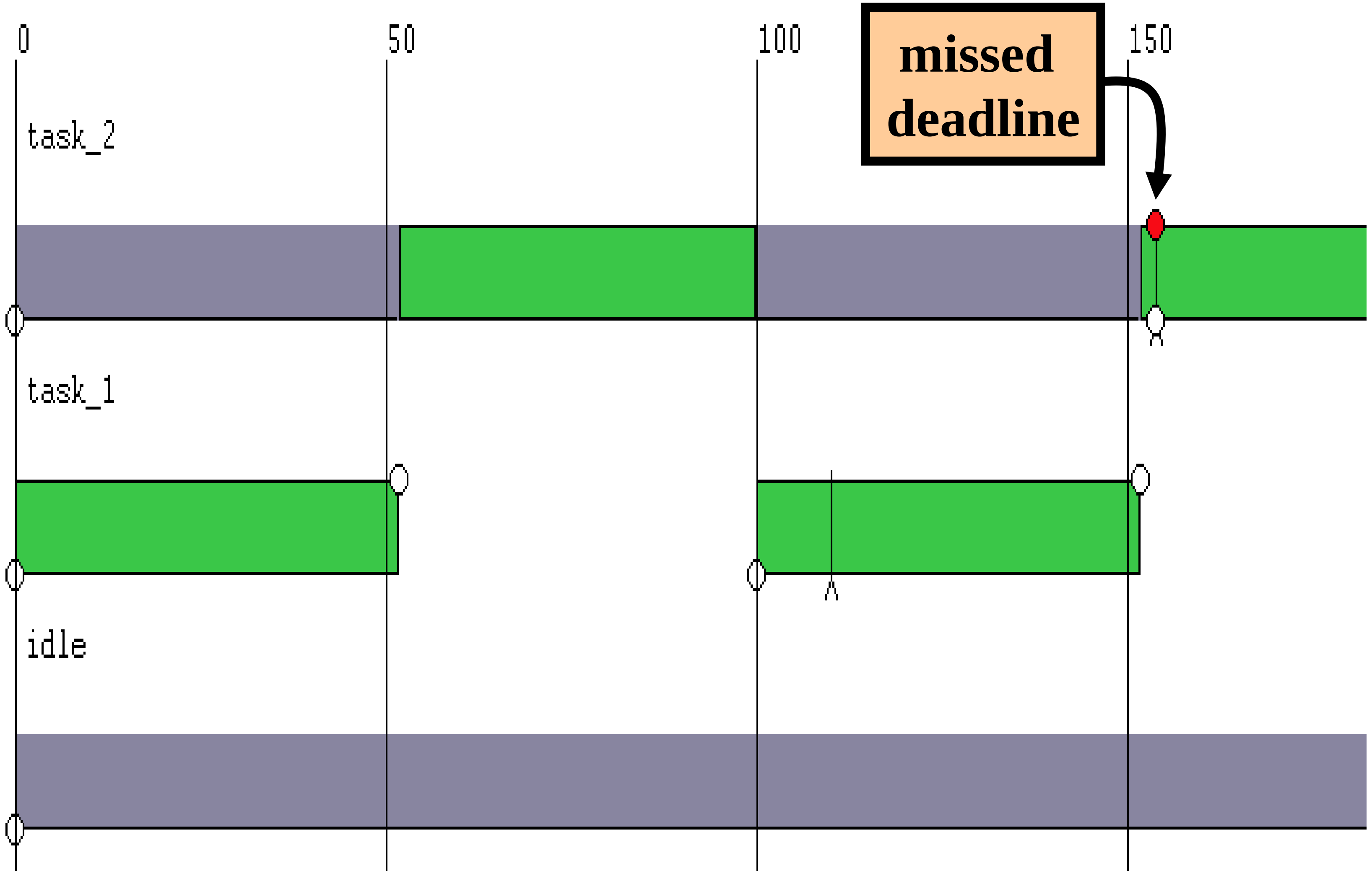
- If $D_i \leq T_i$, then Deadline Monotonic Scheduling Algorithm is optimal.
- If $D_i > T_i$, this may not be true.

Example: task 1 w/ highest priority

```
/* Example */
system
  node node_1
    processor proc_1

      periodic task_1
        period 100 deadline 110 offset 0
        priority 1
        [52,52]
      endper

      periodic task_2
        period 140 deadline 154 offset 0
        priority 2
        [52,52]
      endper

    endpro
  endnod
endsys
```

High Priority

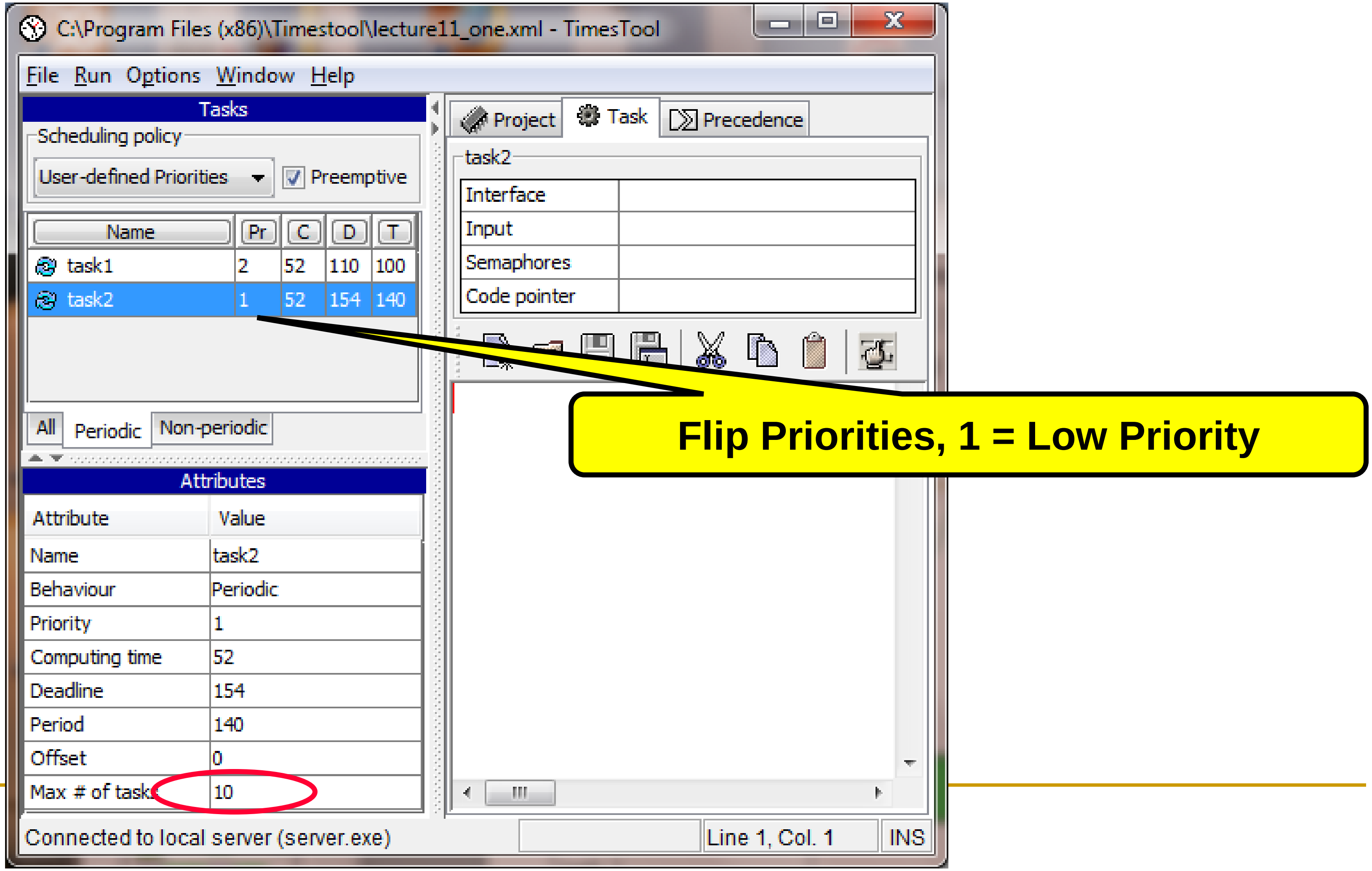
Example: task 1 w/ highest priority



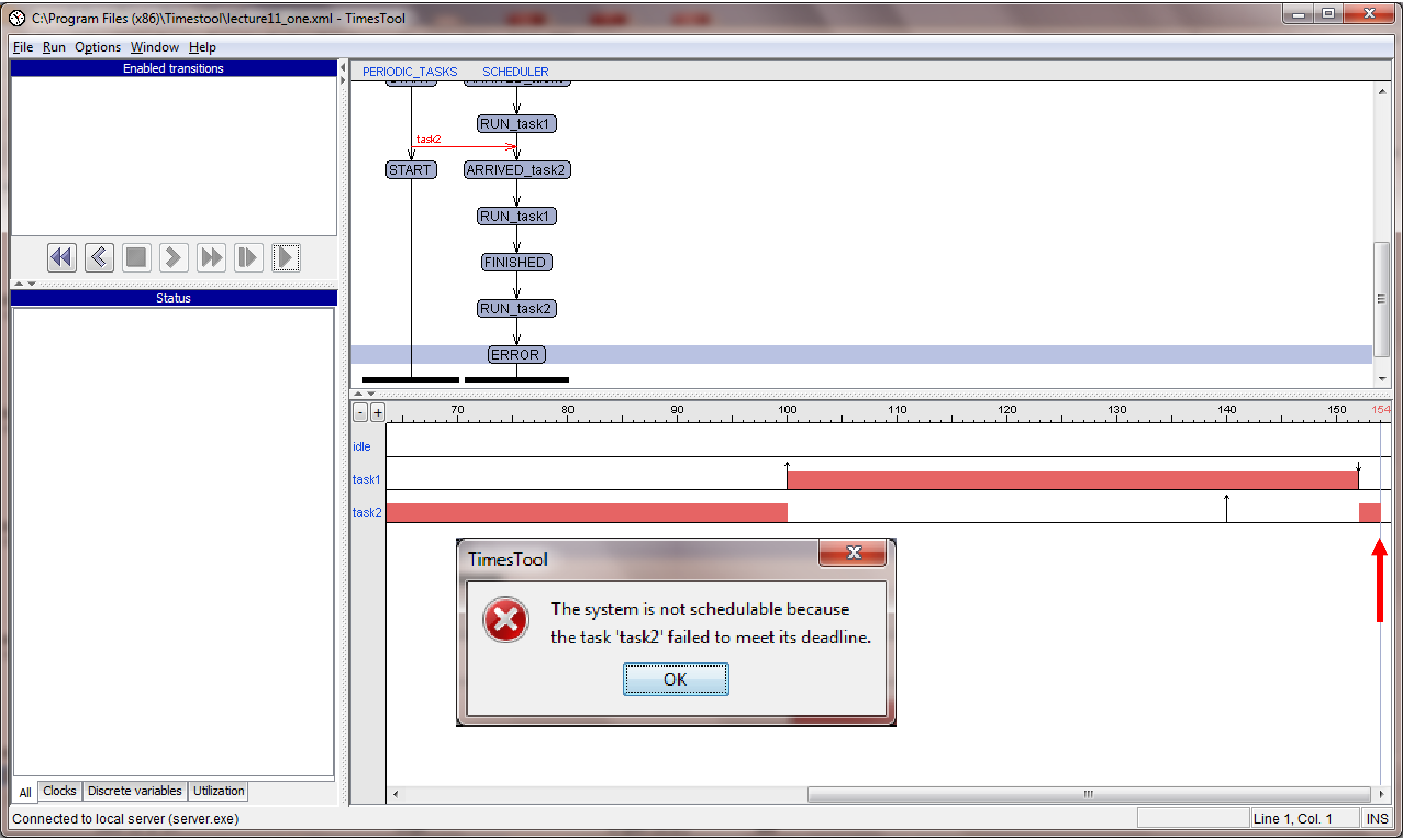
TimesTool - www.timestool.com

Using TimesTool – java –jar timestool.jar

- http://www.timestool.com and online



TimesTool Simulation Output

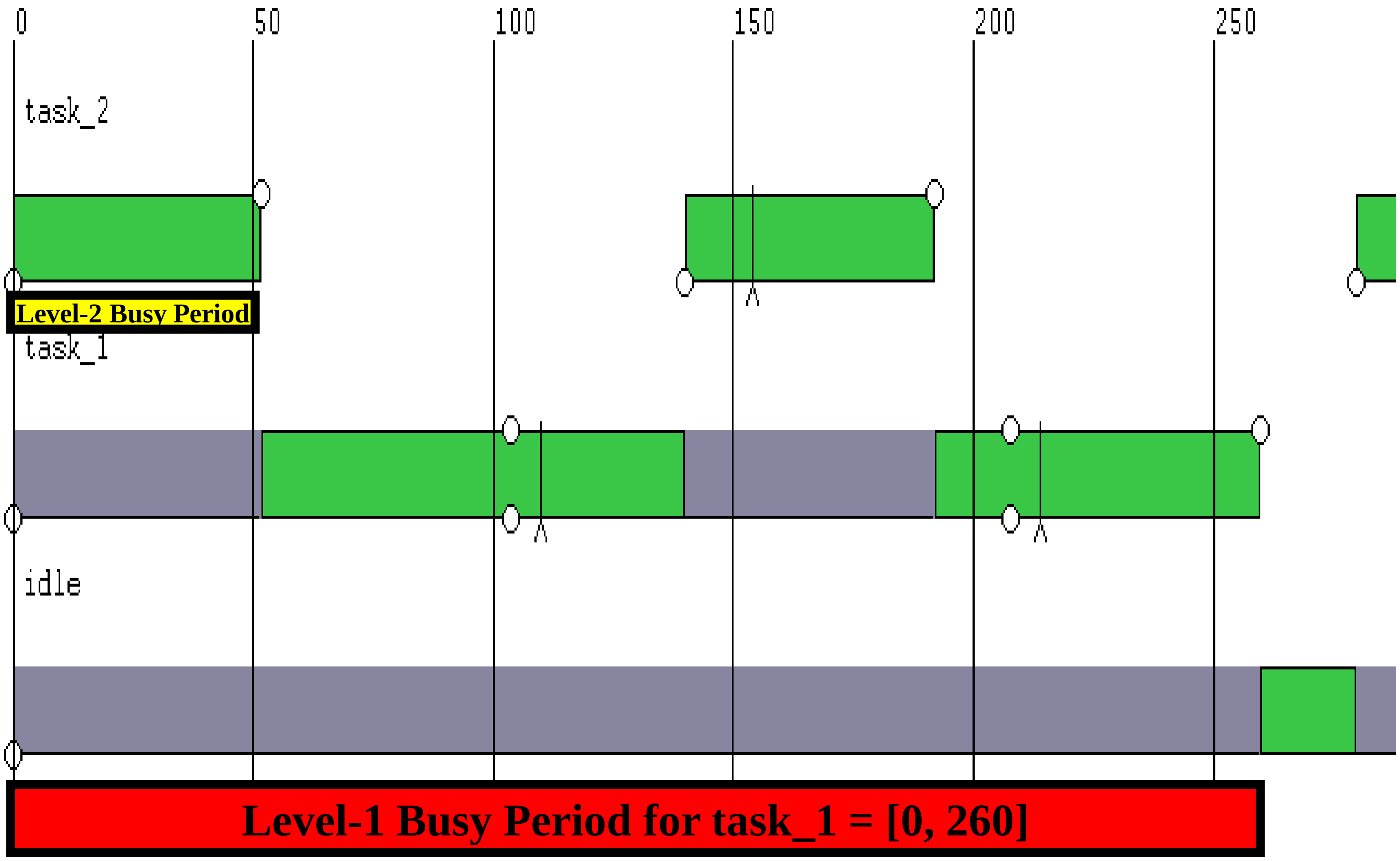


Example: task 2 w/ highest priority

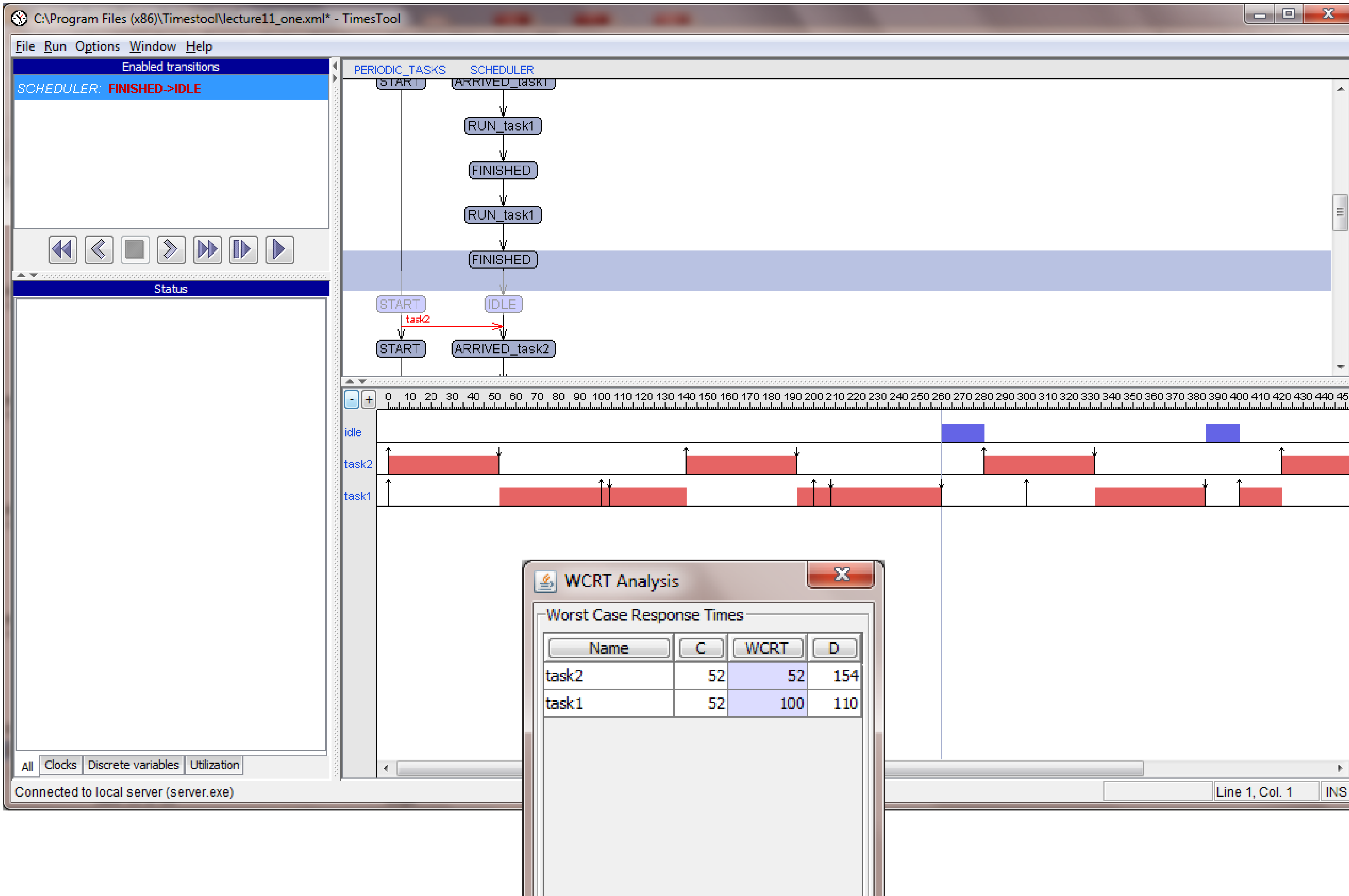
```
/* Example */
system
  node node_1
    processor proc_1

      periodic task_1
        period 100 deadline 110 offset 0
        priority 2
        [52,52]
      endper

      periodic task_2
        period 140 deadline 154 offset 0
        priority 1
        [52,52]
      endper

    endpro
  endnod
endsys
```

High Priority

Example: task 2 w/ highest priority



TimesTool Output



Response Time Analysis

- For each (potentially overlapping) release, a worst-case completion time $w_i(q)$ is defined by:

$$w_i^{n+1}(q) = q \cdot C_i + \sum_{j \in hp(i)} \left\lceil \frac{w_i^n(q)}{T_j} \right\rceil \cdot C_j$$

$$w_i^0(q) = C_i + (q-1) \cdot T_i$$

  where q is the instance or job number and $w_i(q)$ is the least fixed point of $w^n{}_i(q)$.

- The response time of the q^{th} instance, $R_i(q)$, is given by $R_i(q) = w_i(q) - (q-1)\ T_i$.

Response Time Analysis (cont.)

- Set $q' = \min \{ q \mid R_i(q) \leq T_i \}$.
- Then, the **level-i busy period** is $[\ 0, w_i(q')\ ]$.
- The **worst-case response time** R_i is given by:

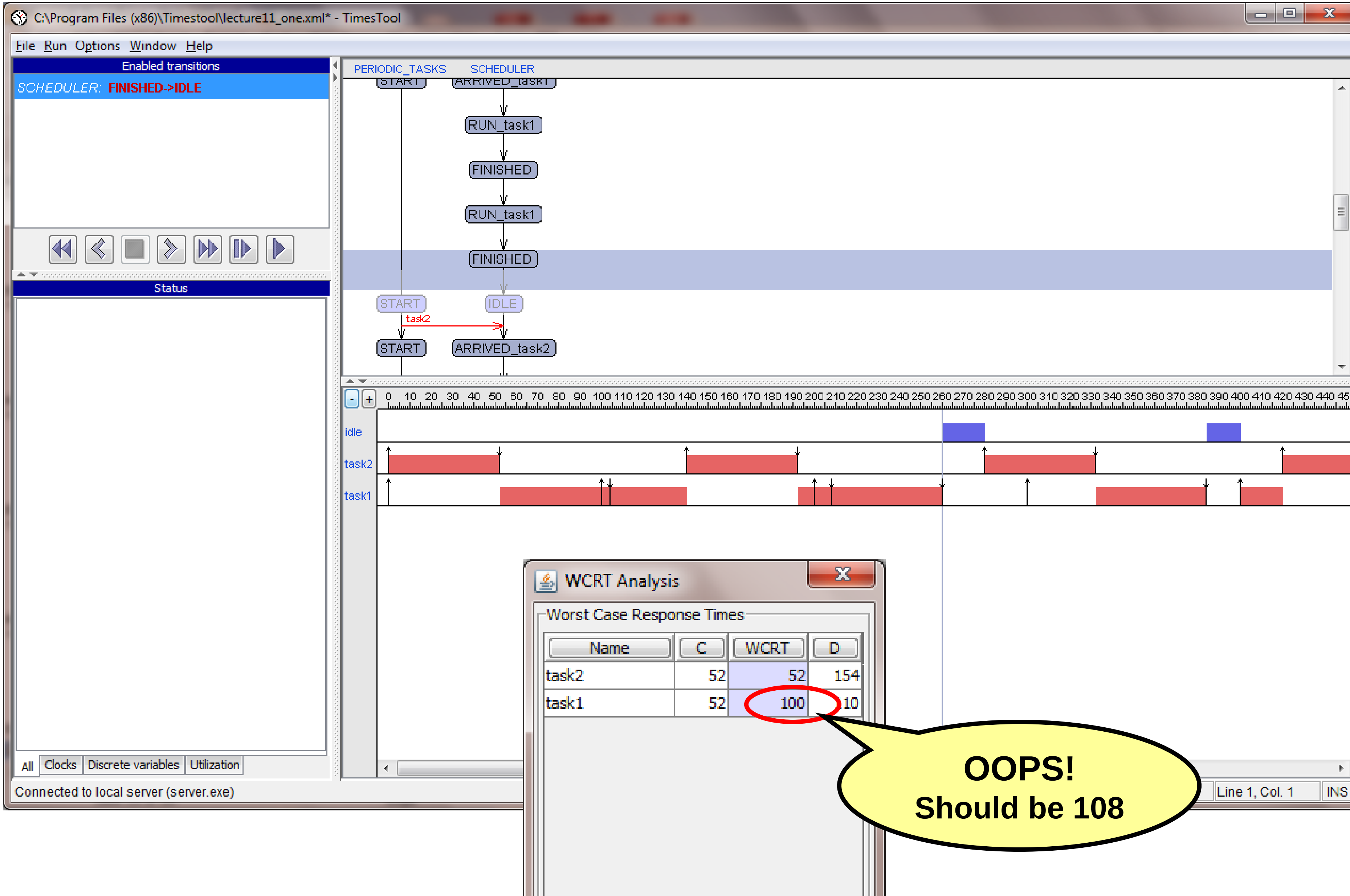
$$R_i = \max_{q=1,2,..,q'} \{R_i(q)\}$$

  - If $R_i \leq D_i$ for all i, the system is **schedulable**.

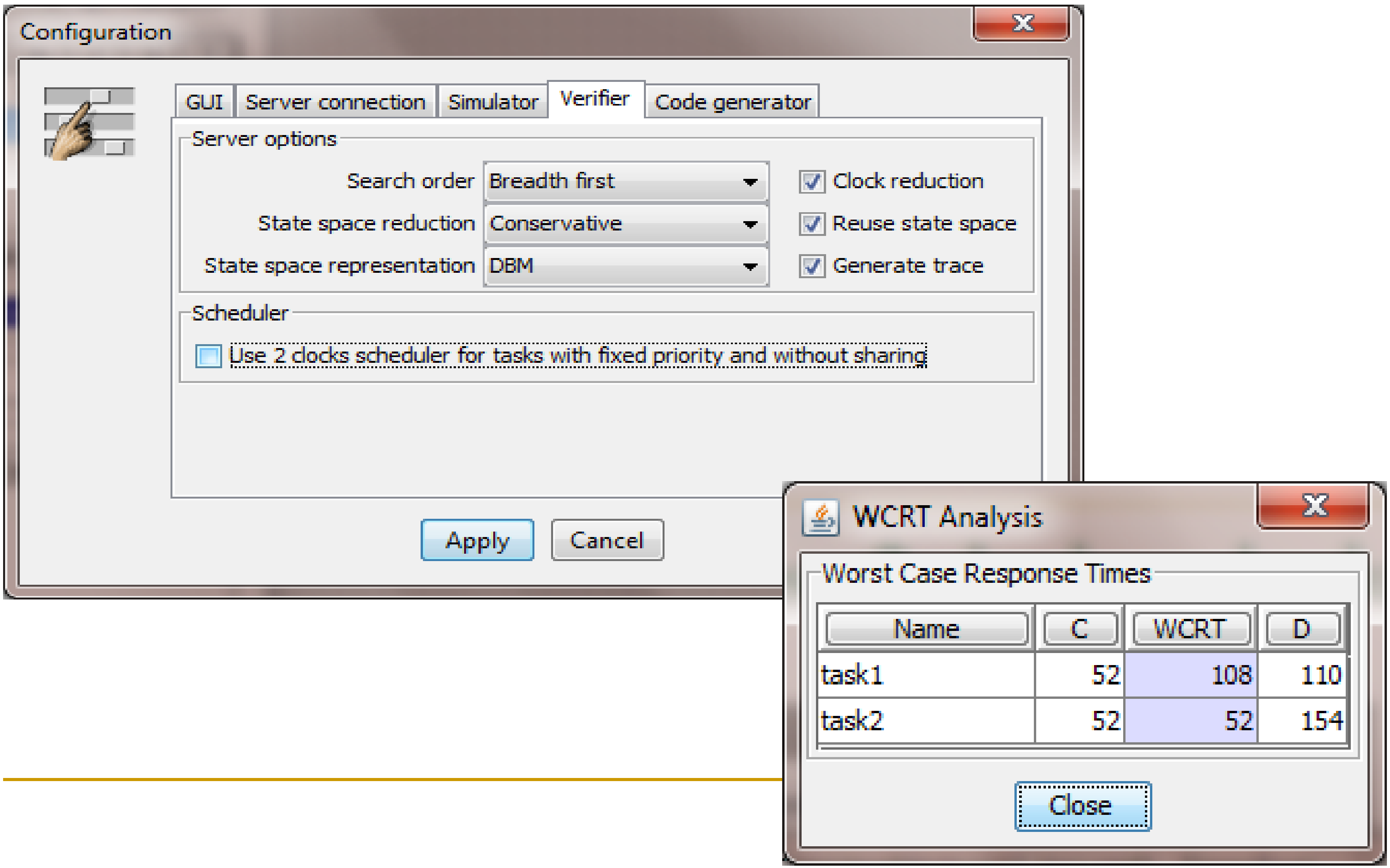
Example #9

Task τ_i	Period T_i	Deadline D_i	Run-Time C_i	Phase φ_i
τ_1	100	110	52	0
τ_2	140	154	52	0

TimesTool Output



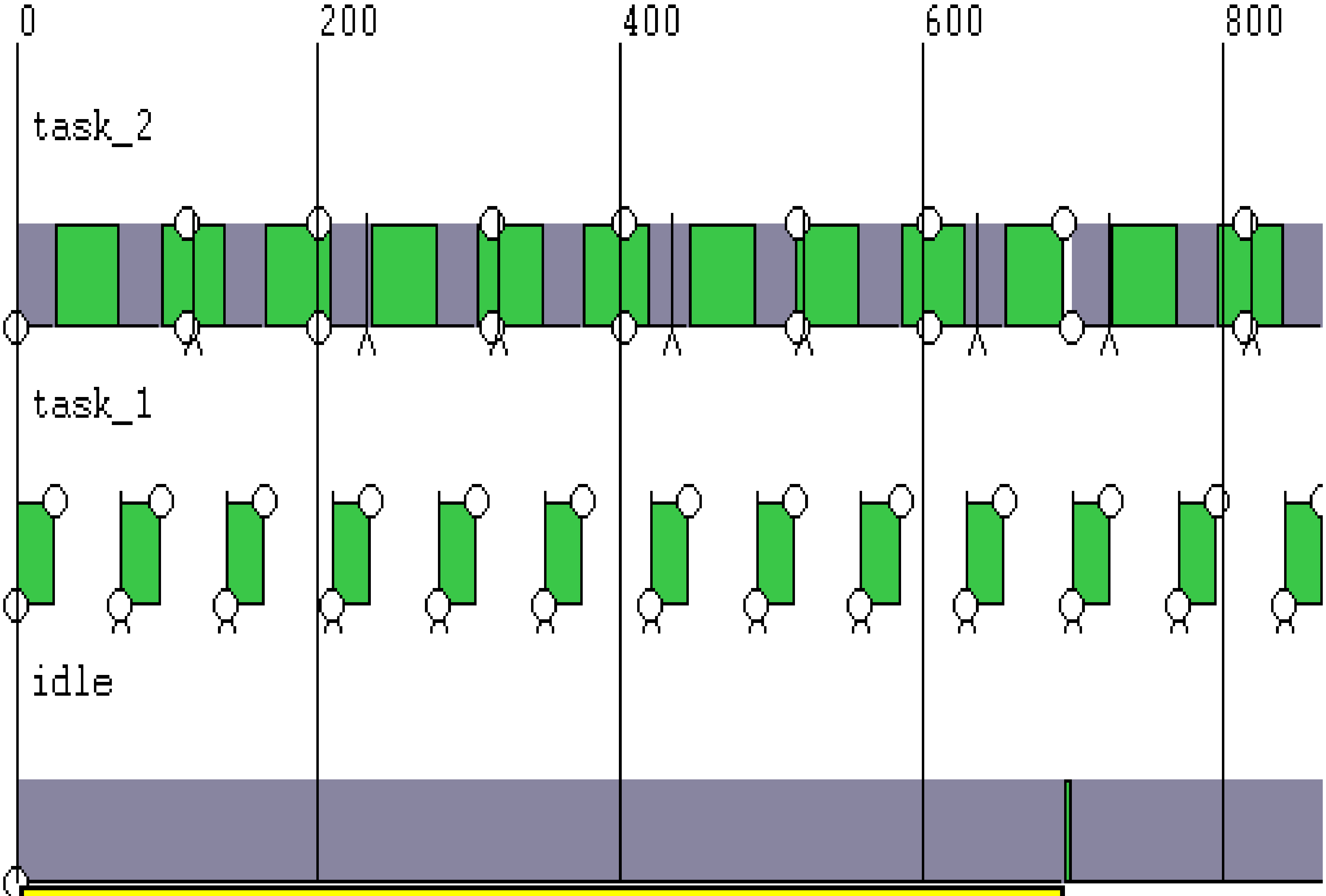
Hack: Don't use 2 clocks scheduler…



Lehoczky's Example

Task τ_i	Period T_i	Run-Time C_i	Phase φ_i	Deadline D_i
τ_1	70	26	0	68
τ_2	100	62	0	118

114, 102, 116, 104, 118, 106, 94 - task_2 WCRT



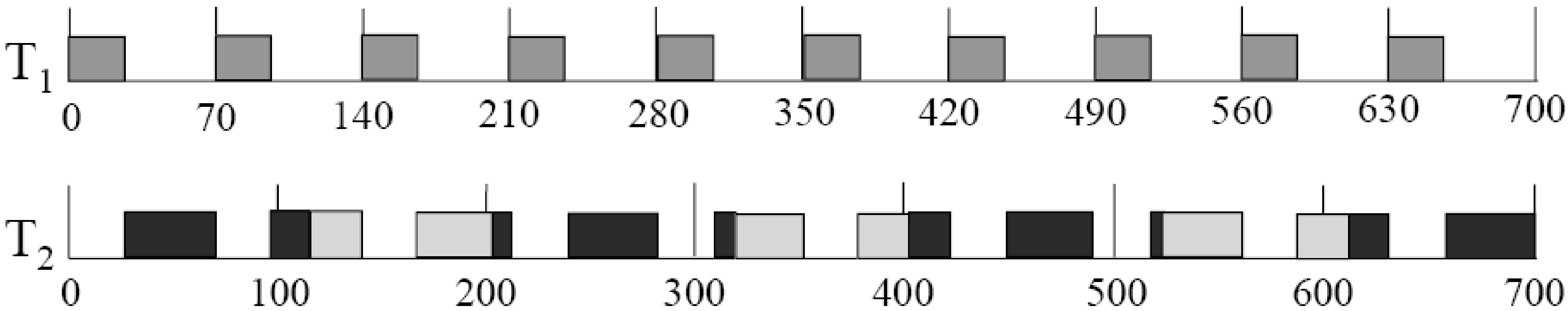
Level-i Busy Period for task_2 = [0, 694]

General Time-Driven Analysis

- Check to see if the first job completes before it’s deadline and before the second job in the same task is released.
- If not, check all jobs over a level-i busy period.

Example

$$T_1 = (70, 26),\ T_2 = (100, 62)$$



$$W_{2,1} = \text{minimum t s.t.}$$

$$t = w_{2,1}(t)$$

$$= e_2 + \sum_{k=1}^{i-1} \left\lceil \frac{t}{p_k} \right\rceil \cdot e_k$$

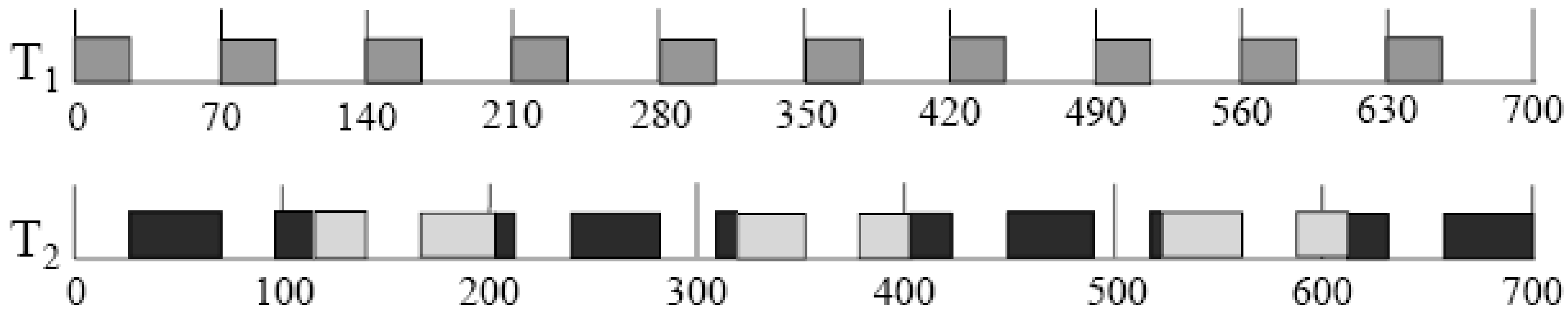
$$= 62 + \left\lceil \frac{t}{70} \right\rceil \cdot 26$$

$$??114 = 62 + \left\lceil \frac{114}{70} \right\rceil \cdot 26$$

$$= 62 + 2 \cdot 26$$

$$= 114 \quad \text{Yes!}$$

Example (cont.)



$$W_{2,2} = \text{minimum t s.t.}$$

$$t = w_{2,2}(t + p_2) - p_2$$

$$= 2 \cdot e_2 + \sum_{k=1}^{i-1} \left\lceil \frac{t+100}{p_k} \right\rceil \cdot e_k - 100$$

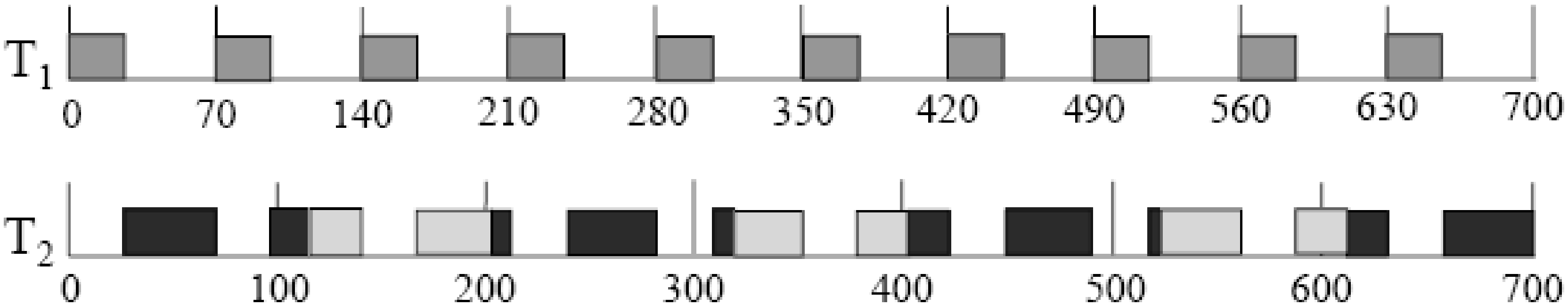
$$= 124 + \left\lceil \frac{t+100}{70} \right\rceil \cdot 26 - 100$$

$$??\ 102 = 124 + \left\lceil \frac{202}{70} \right\rceil \cdot 26 - 100$$

$$= 124 + 3 \cdot 26 - 100$$

$$= 102 \quad \text{Yes!}$$

Example (cont.)



$$W_{2,3} = \text{minimum } t \text{ s.t.}$$

$$t = w_{2,3}(t + 2 \cdot p_2) - 2 \cdot p_2$$

$$= 3 \cdot e_2 + \sum_{k=1}^{i-1} \left\lceil \frac{t+200}{p_k} \right\rceil \cdot e_k - 200$$

$$= 186 + \left\lceil \frac{t+200}{70} \right\rceil \cdot 26 - 200$$

$$??116 = 186 + \left\lceil \frac{316}{70} \right\rceil \cdot 26 - 200$$

$$= 186 + 5 \cdot 26 - 200$$

$$= 116 \quad \text{Yes!}$$

Summary

- Read Ch. 5-7, next time start on Ch. 8.
- Read Audsley's paper on scheduling with arbitrary start times.
- Read Lehoczky's paper on scheduling with arbitrary deadlines.