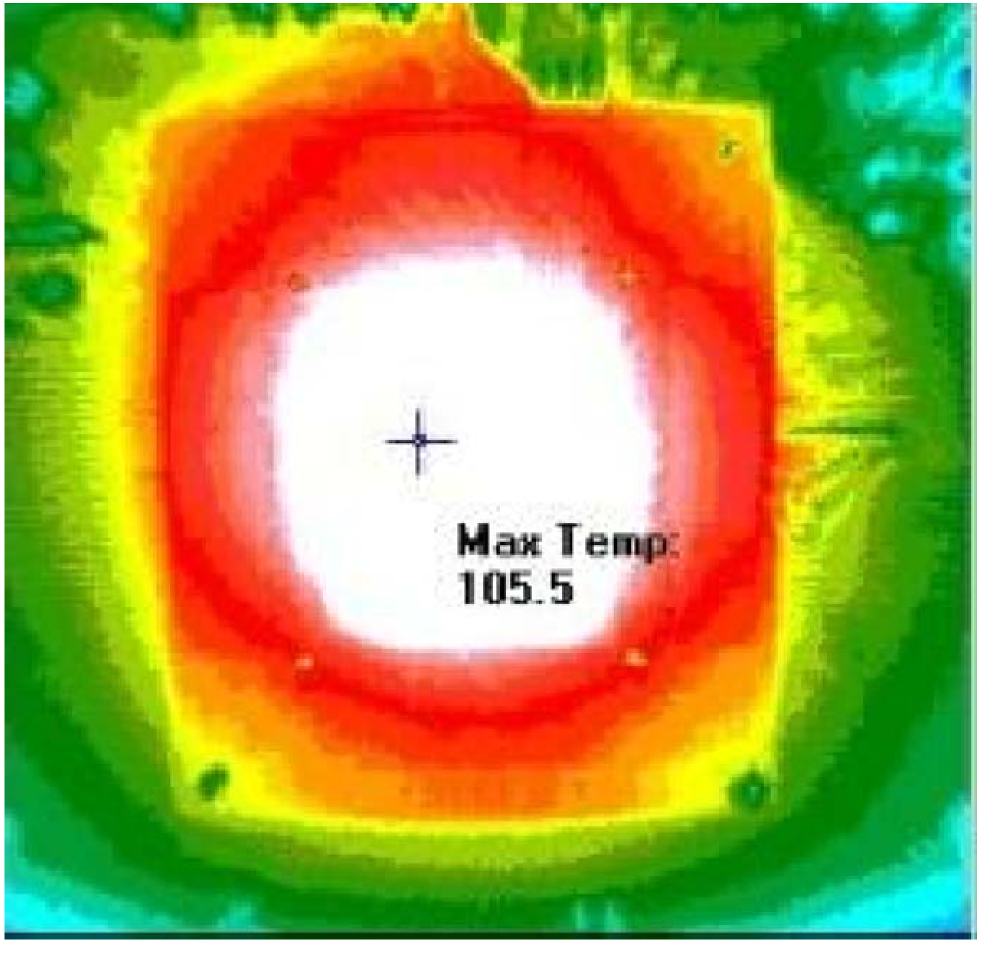
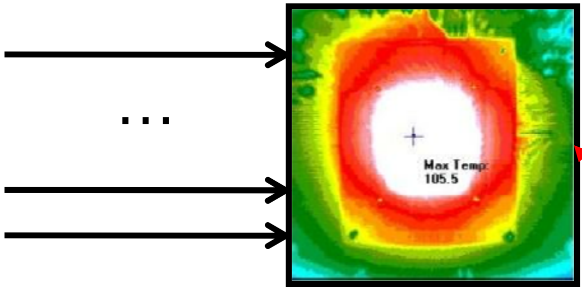
When does it get hot?

© ***Lothar Thiele***, Iuliana Bacivarov, Jian-Jia Chen, Devendra Rai, Hoeseok Yang


Max Temp:
105.5



bound on event arrivals

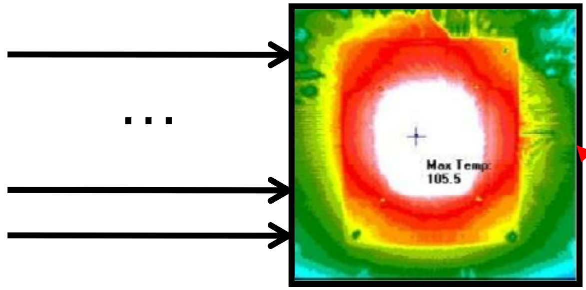
period: 120 ms

jitter: 240 ms

interarrival: 30 ms

workload model

execution time: 30ms



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peak temperatures

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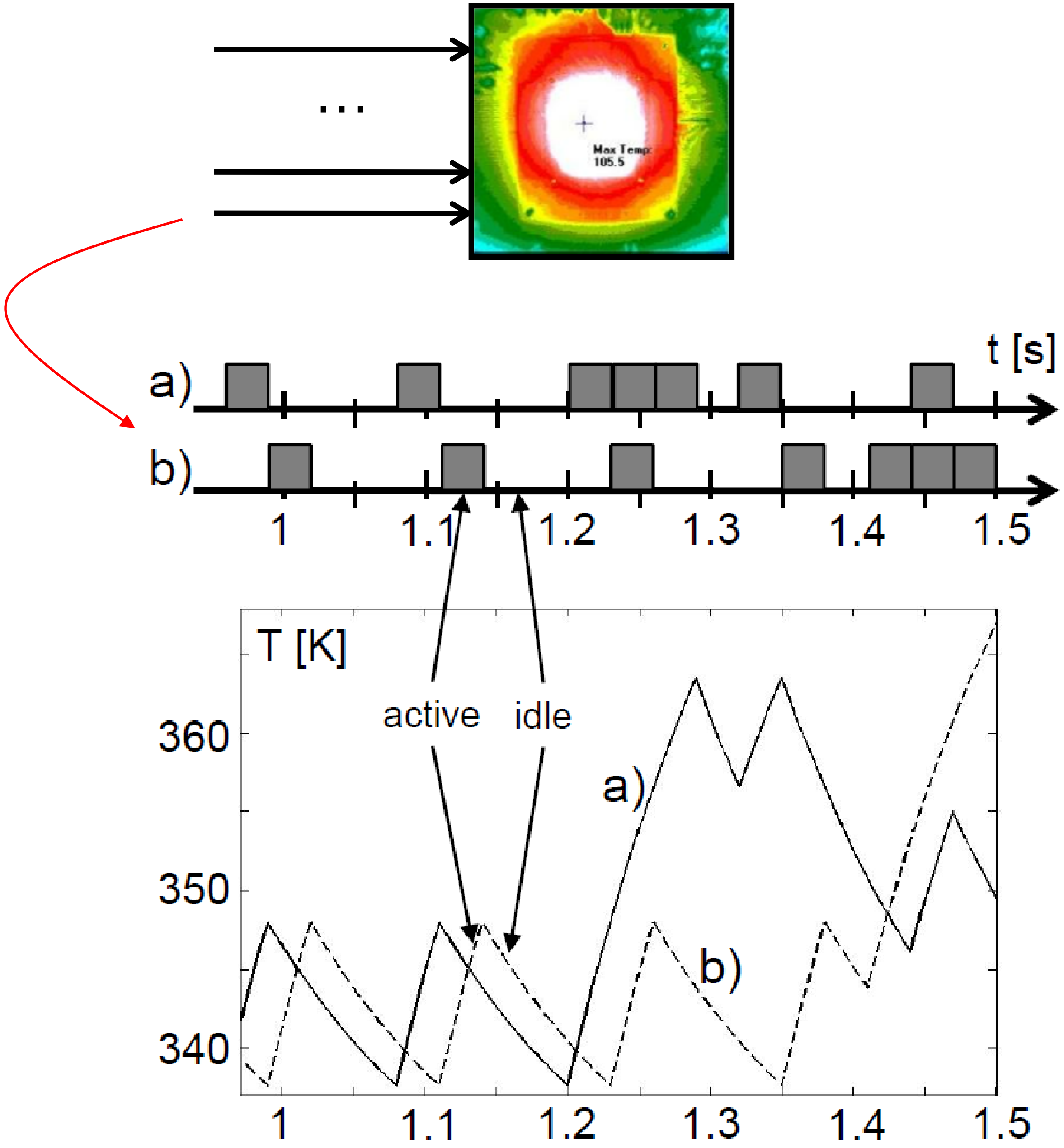
worst case:	366.9 K



heuristic

worst case

Given

- a bound on workload arrivals (arrival curves)
- a computation model (from workload to task executions)
- a power model (from task executions to power)
- a temperature model (from power to temperature)

What is the worst case peak temperature?

The Models

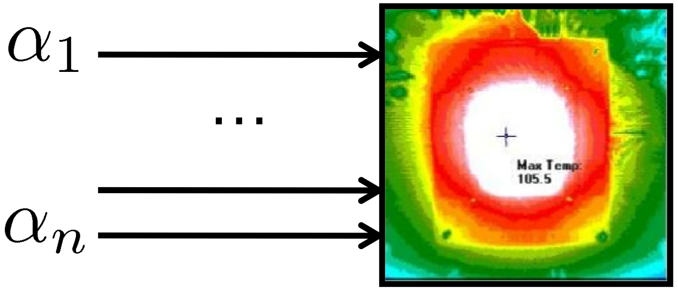
Workload Arrival Model

- *Cumulative workload:* In time interval [s, t), tasks with an accumulated workload of R(s,t) arrive.
- *Arrival curve:* The cumulative workload is upper bounded by the arrival curve:

$$R(s,t) \leq \alpha(t-s) \qquad \forall s < t$$

- *Multiple inputs:*

$$\alpha(\Delta) = \sum_{\text{inputs } i} \alpha_i(\Delta)$$

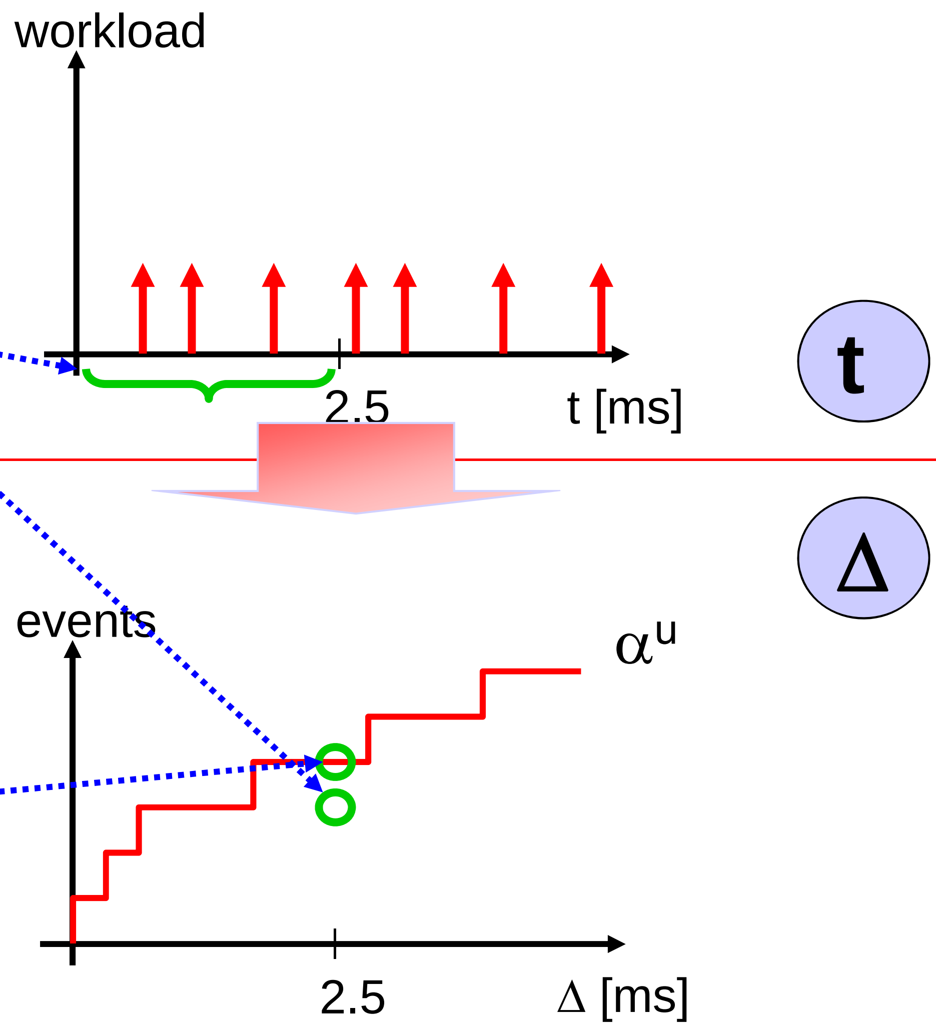


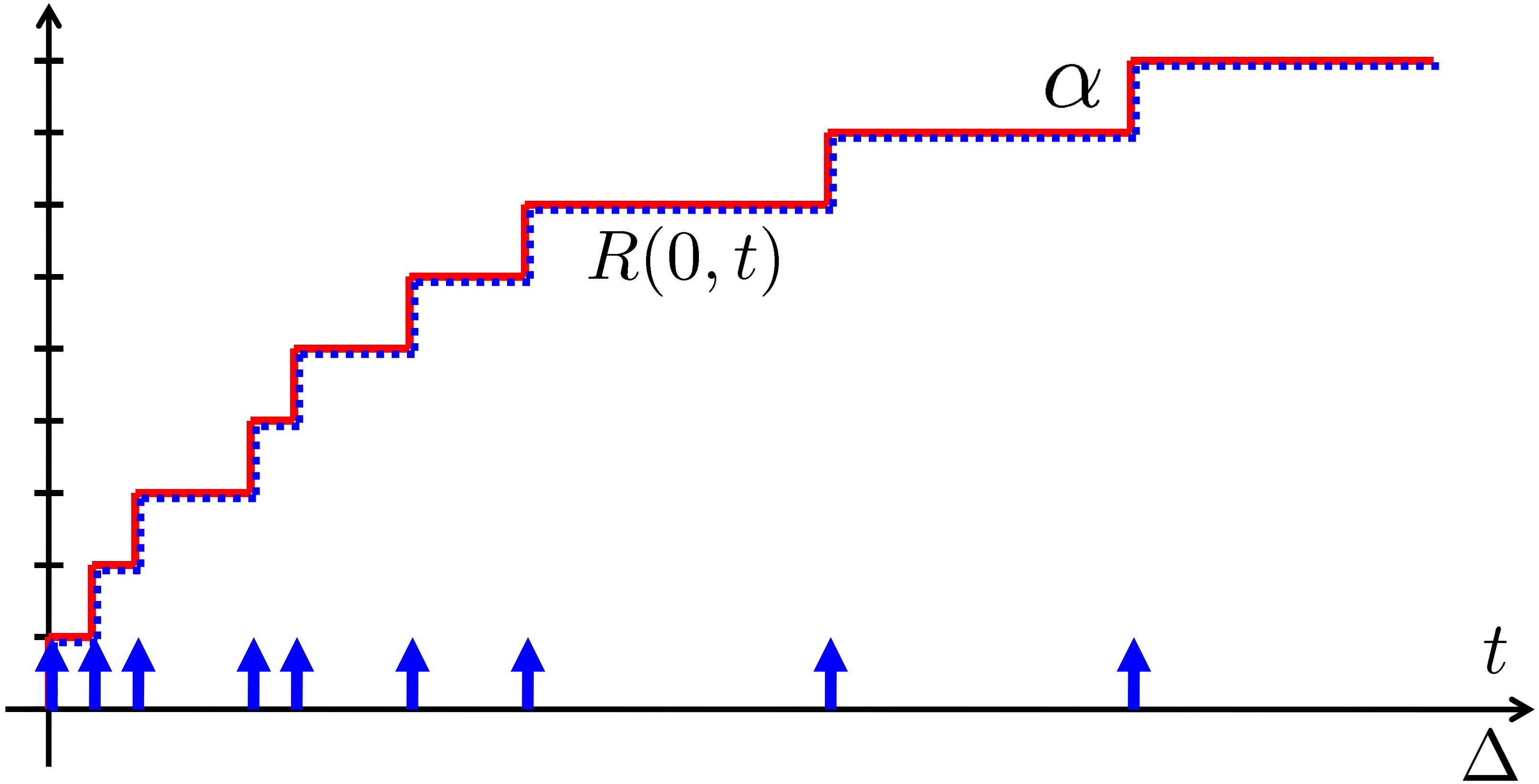
Event Stream

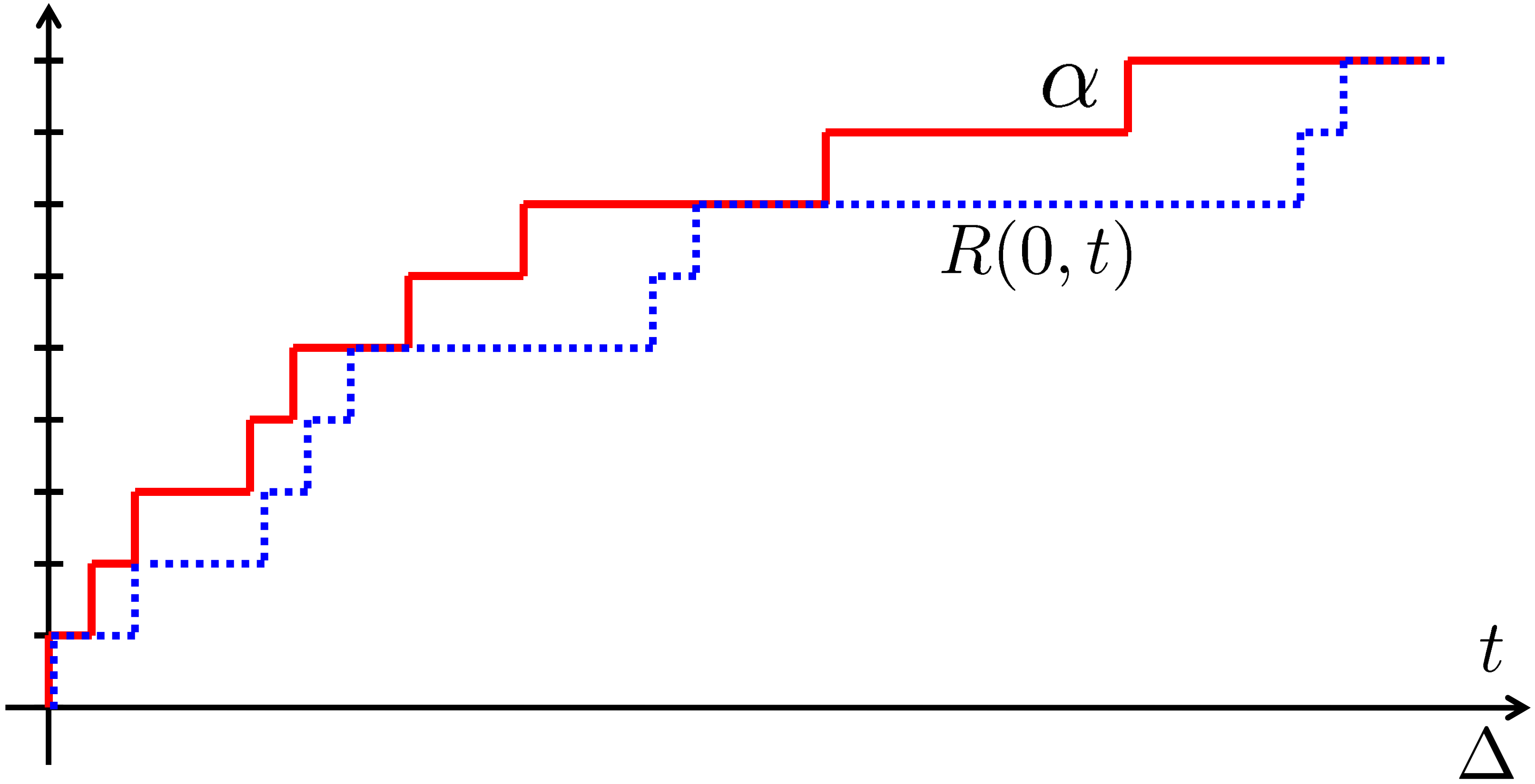
$R(0,2.5)$: total workload in t=[0 .. 2.5] ms

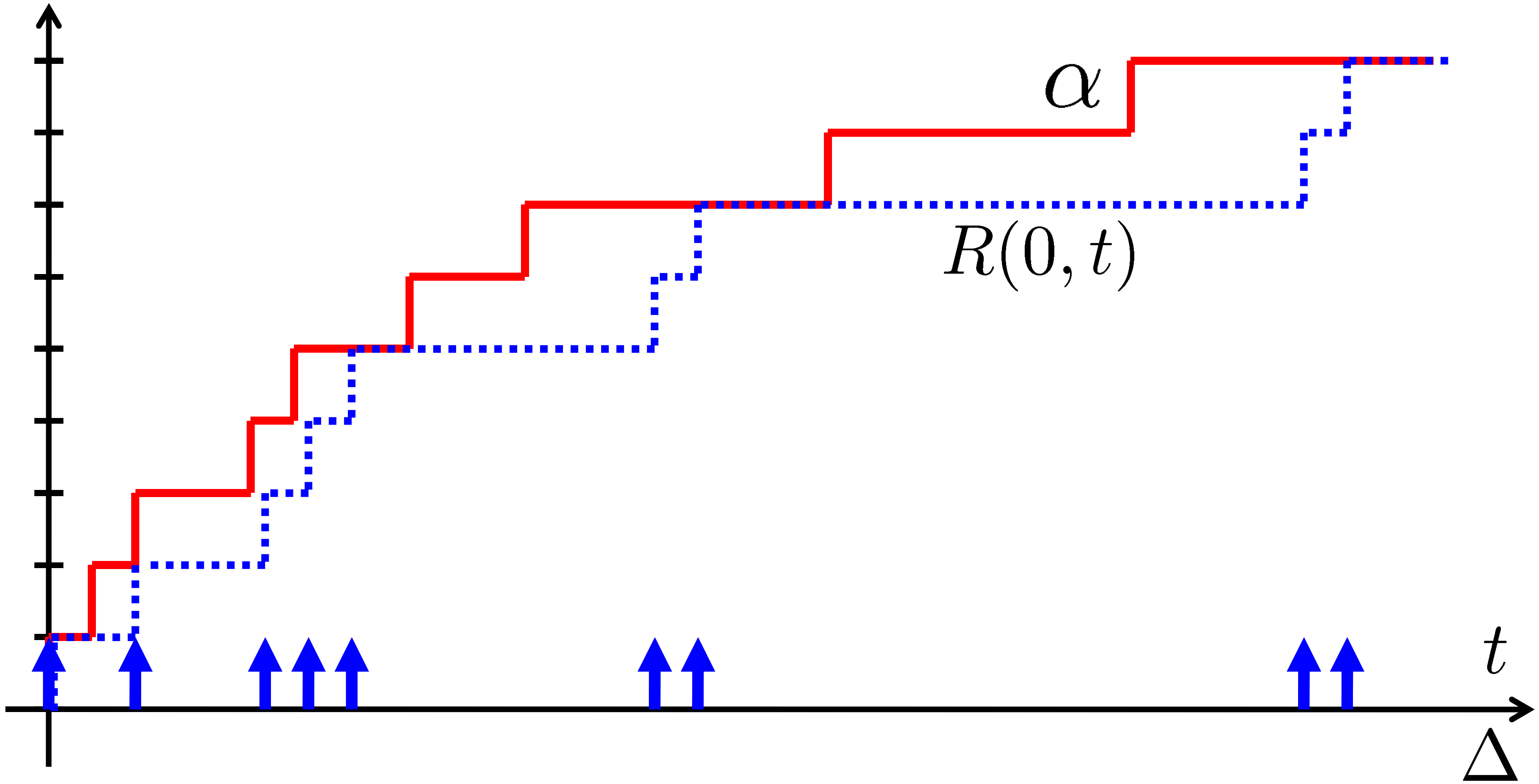
Arrival Curve α

maximum workload in *any interval* of length 2.5 ms

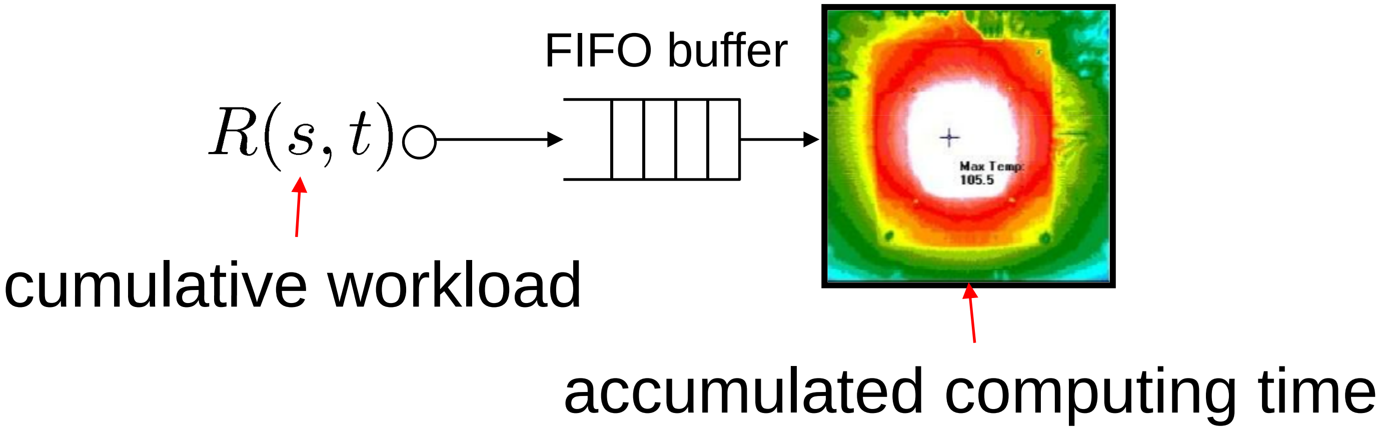



α
$R(0,t)$
t
Δ

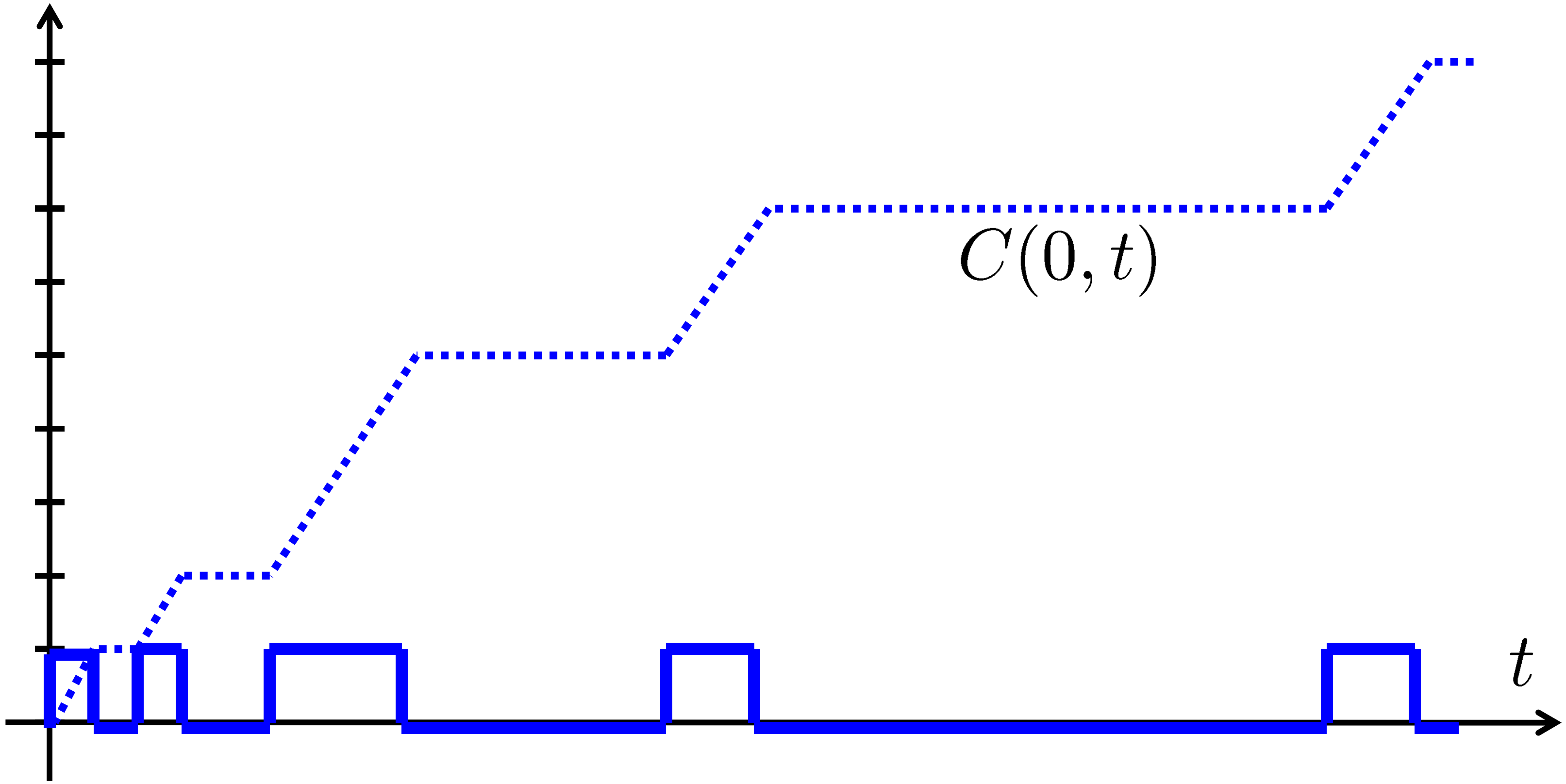

α
$R(0,t)$
t
Δ


α
$R(0,t)$
t
Δ

- ***Computation Model***
  - Arriving workload is buffered in FIFO
  - ***Work conserving schedule*** (EDF, FP, GPS, …)



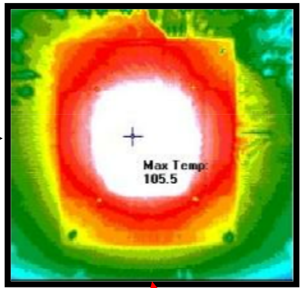
$$C(s,t) = \inf_{s \le u \le t} \{(t-u) + R(s,u)\}$$


$C(0,t)$
t

Computation Model

- Bound on the computing time

$\alpha(\Delta)$ → FIFO buffer →

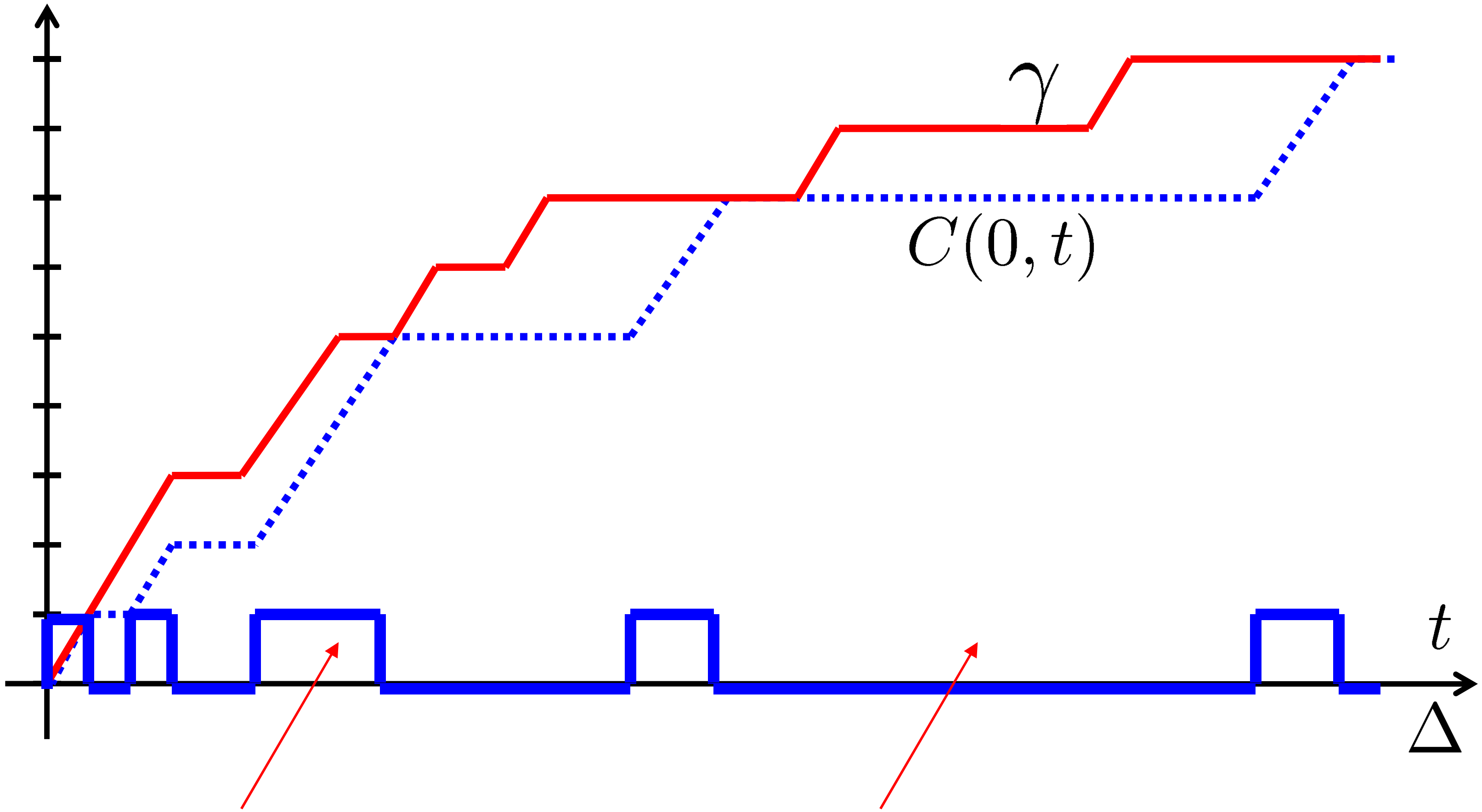


arrival curve

(tight!) computing time bound

$$C(t-\Delta,t) \le \gamma(\Delta) = \inf_{0\le\lambda\le\Delta}\{(\Delta-\lambda)+\alpha(\lambda)\}$$

Given bound on task arrivals α :
all feasible accumulated computing times are bounded by γ



active mode idle mode

- ***Power Model***
  - active and idle modes

$$P^a = \alpha^a T + \beta^a \quad P^i = \alpha^i T + \beta^i$$

temperature-dependent leakage

- ***Temperature Model***

$$C\frac{dT}{dt} = -(G - \alpha)T + (\beta + GT^0)$$

environment temperature

thermal conductance

thermal capacity

What is the worst-case task arrival sequence that leads to maximal peak temperature?

The Results

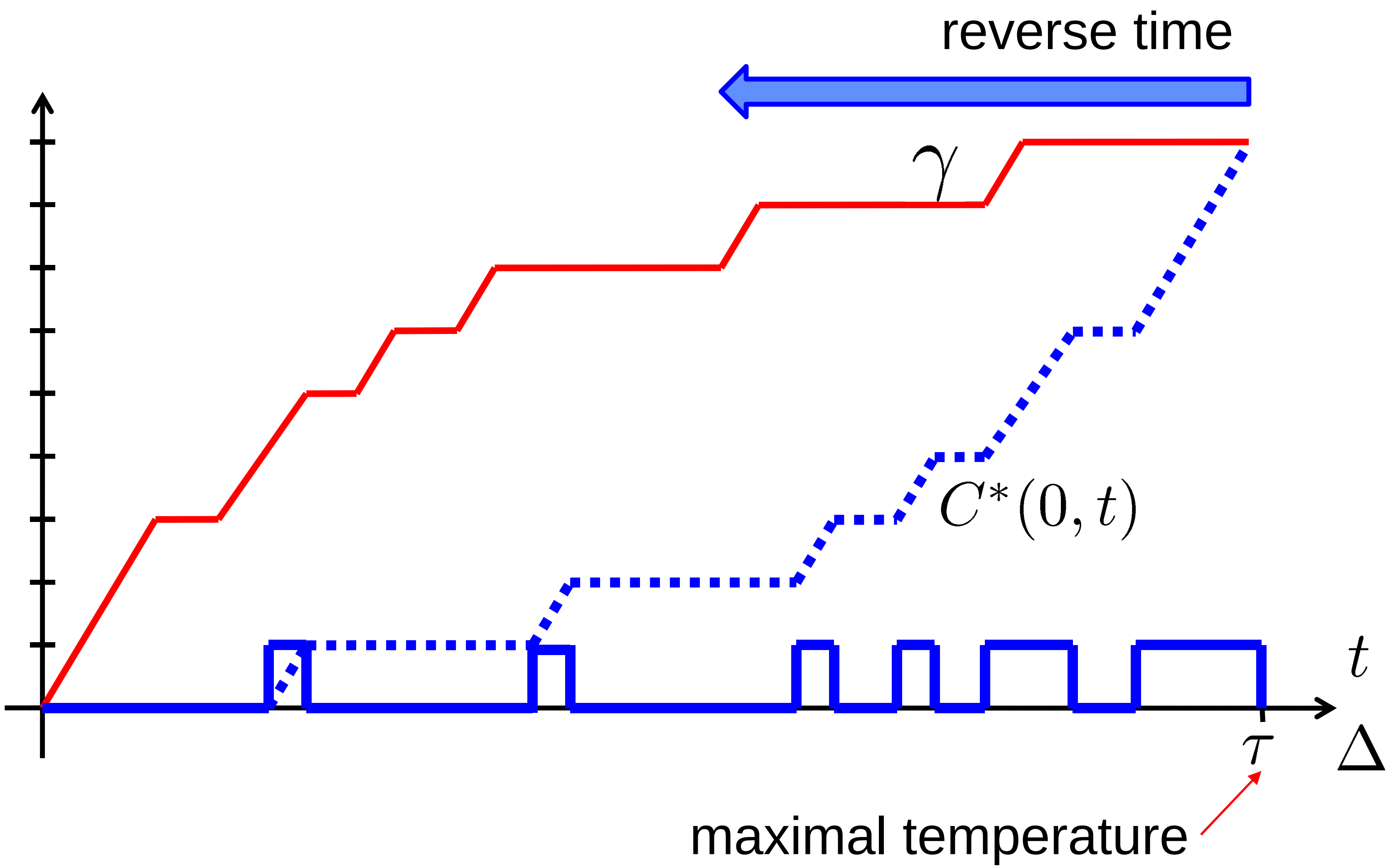
Suppose that the accumulated computing time function

$$C^*(0, \Delta) = \gamma(\tau) - \gamma(\tau - \Delta)$$

for all $0 \leq \Delta \leq \tau$ leads to temperature $T^*(\tau)$ at time τ. Then $T^*(\tau)$ is an upper bound on the highest temperature

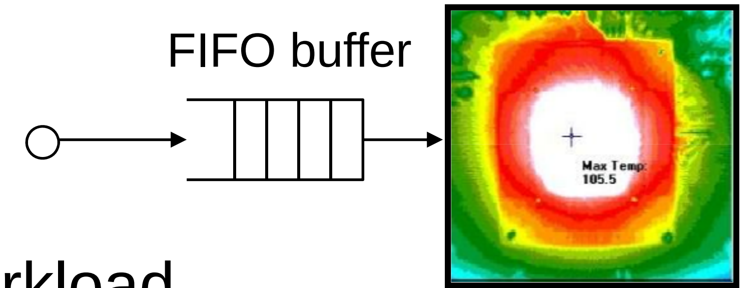
$$T^*(\tau) \geq T(t)$$

for all $0 \leq t \leq \tau$ for all feasible workload traces that are bounded by the service curve α.


reverse time
γ
$C^*(0,t)$
t
τ
Δ
maximal temperature

Does there exist a feasible input trace that leads to the peak temperature ?

$R^*(s,t)$



w.c. cumulative workload

$C^*(s,t)$

w. c. accumulated computing time

The worst-case workload function

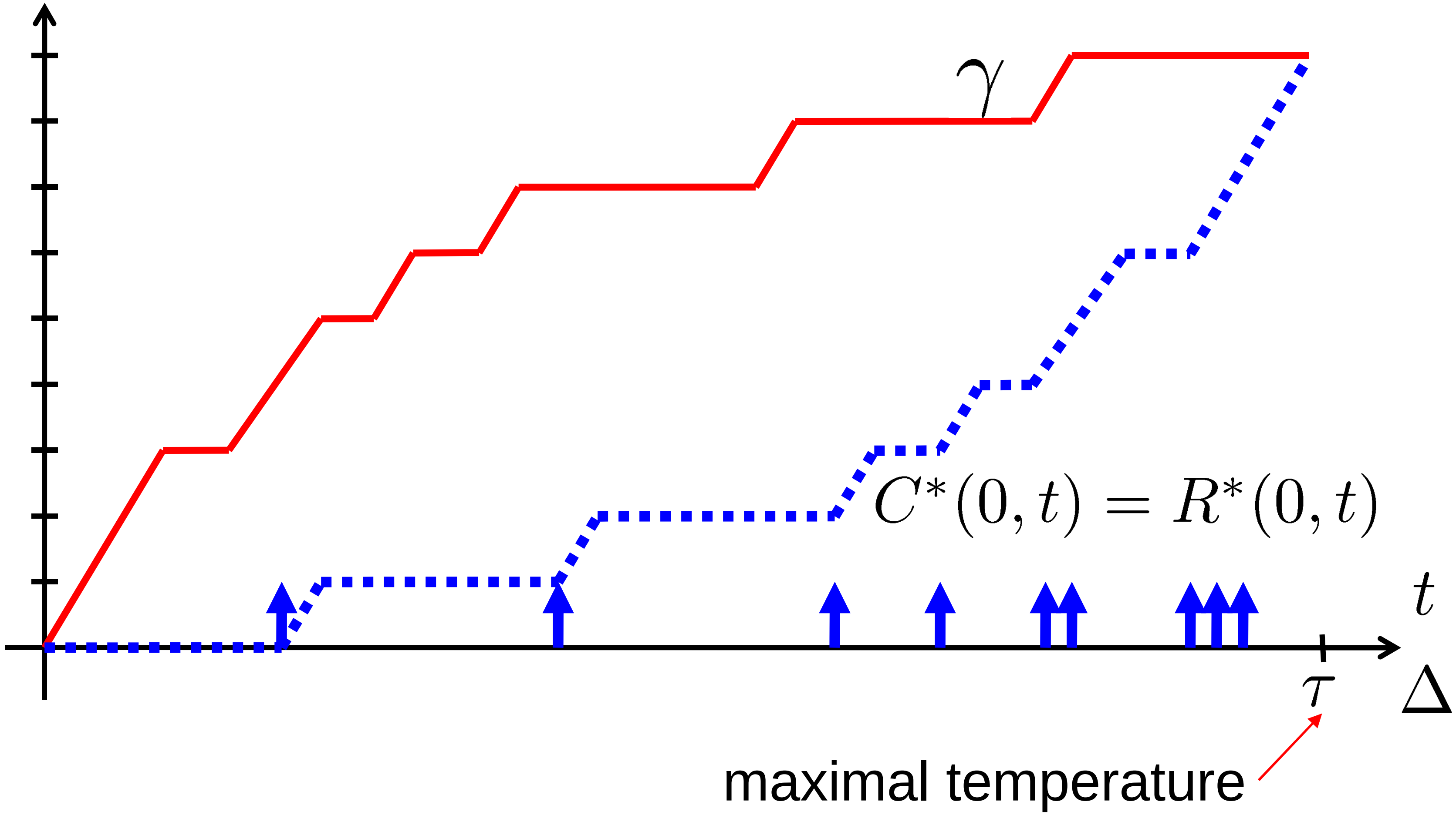
$$R^*(0, \Delta) = C^*(0, \Delta)$$

for $0 \leq \Delta \leq \tau$ leads to the accumulated computing time $C^*(0, \Delta)$ and complies to the arrival curve α.

If the step size of $\alpha(\Delta)$ is an integer multiple of c then

$$\hat{R}^*(0, \Delta) = c \cdot \lceil \frac{1}{c} R^*(0, \Delta) \rceil$$

has stepsize c and is a feasible worst case trace as well.


γ
$C^*(0,t) = R^*(0,t)$
t
τ
Δ
maximal temperature

How large should τ be?

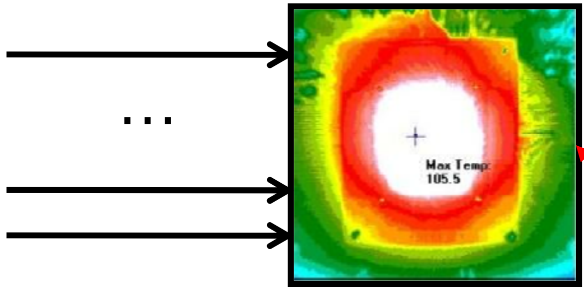
All observation times τ that satisfy the following relation guarantee a peak-temperature precision of $T^a(\tau) - T^i(\tau)$

$$\tau \geq \frac{1}{a^i} \cdot \log \frac{(T^\infty)^a - (T^\infty)^i}{T^a(\tau) - T^i(\tau)}$$

$(T^\infty)^i$ and $(T^\infty)^a$ denote the steady state temperatures in idle and active mode, respectively.

$T^i(\tau)$ and $T^a(\tau)$ denote the temperatures at time τ with initial temperatures $(T^\infty)^i$ and $(T^\infty)^a$, respectively.

Some Simulations



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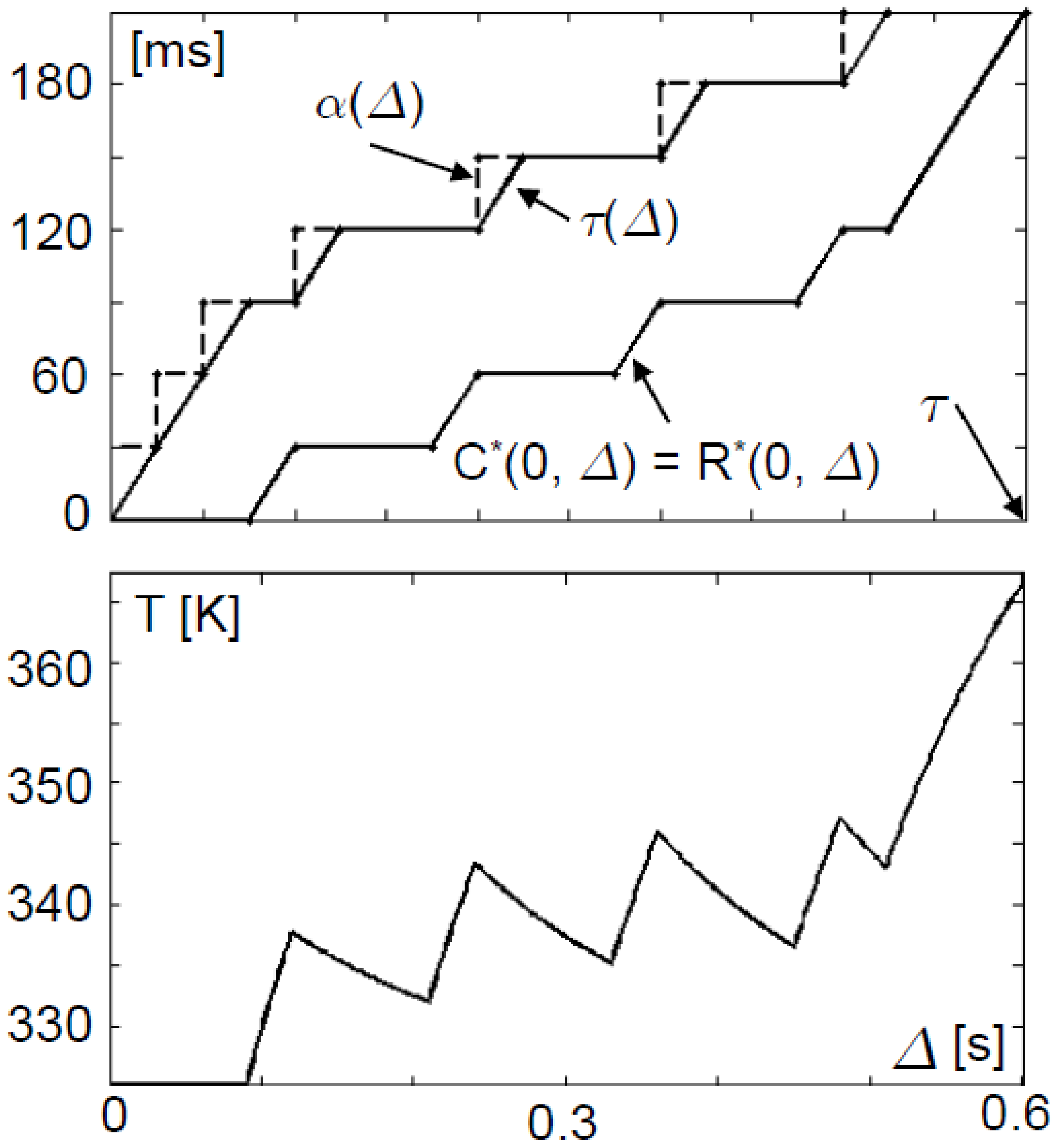
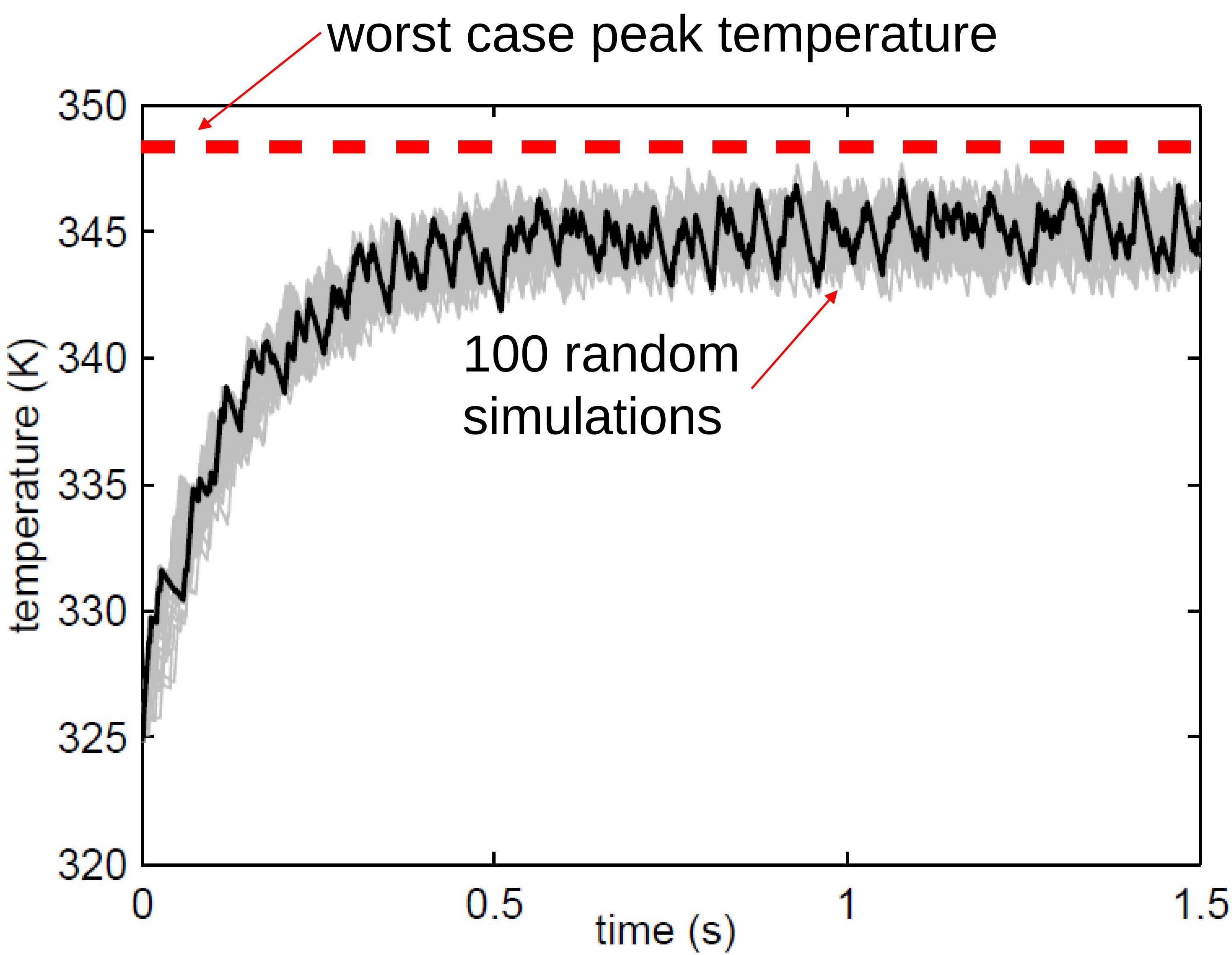

[ms]
180
120
60
0
$\alpha(\Delta)$
$\tau(\Delta)$
$C^*(0, \Delta) = R^*(0, \Delta)$
τ
T [K]
360
350
340
330
Δ [s]
0
0.3
0.6

	Video	Audio	Network
period	[20, 90]ms	30ms	30ms
jitter	[20, 90]ms	10ms	10ms
min. interarrival	1ms	1ms	1ms
execution demand	6ms	3ms	2ms
deadline	[20, 90]ms	30ms	30ms

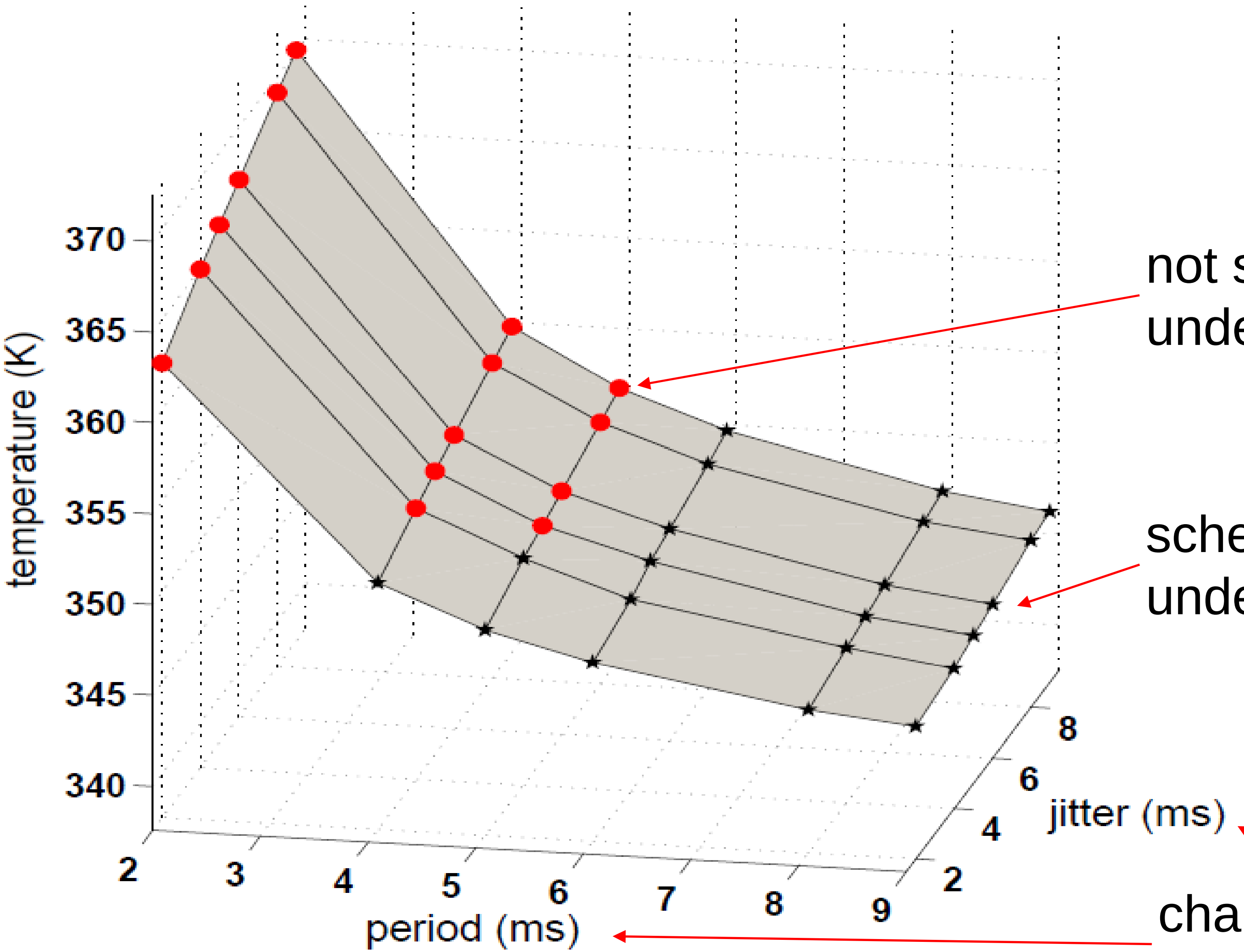
Table I
PARAMETERS OF THE VIDEO CONFERENCING APPLICATION.

G	C	$\alpha^i = \alpha^a$	β^i	β^a	T^o	τ
$0.3\frac{W}{K}$	$0.03\frac{J}{K}$	$0.1\frac{W}{K}$	$-25W$	$-11W$	$300K$	$1.5s$

Table II
PARAMETERS OF THE CONSIDERED EMBEDDED SYSTEM ARCHITECTURE.



worst case peak temperature
350
345
340
335
330
325
320
temperature (K)
100 random
simulations
0
0.5
1
1.5
time (s)



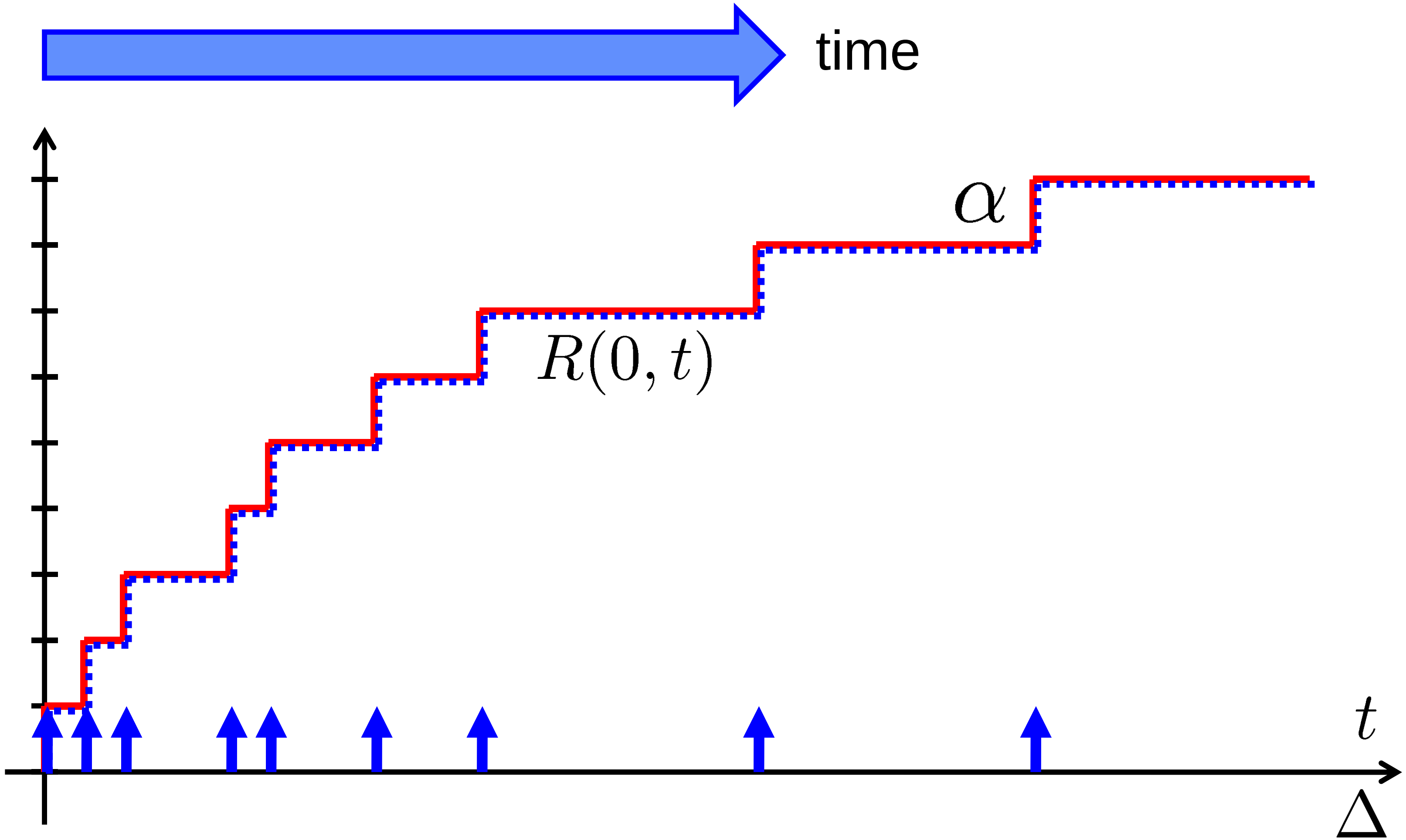
not schedulable
under EDF

schedulable
under EDF

change task
arrival of video

Conclusion

Critical instance for real-time analysis



Critical instance for temperature analysis