FIFO WITH OFFSETS

HIGH SCHEDULABILITY WITH LOW OVERHEADS

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FIFO SCHEDULING

First-In-First-Out (**FIFO**) scheduling

- extremely **simple**
- very **low overheads**

ideal for:
- *IoT-class devices*
- *deeply embedded systems*
- *hardware implementations*

very ***low schedulability*** } meeting **deadlines**?

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THIS PAPER

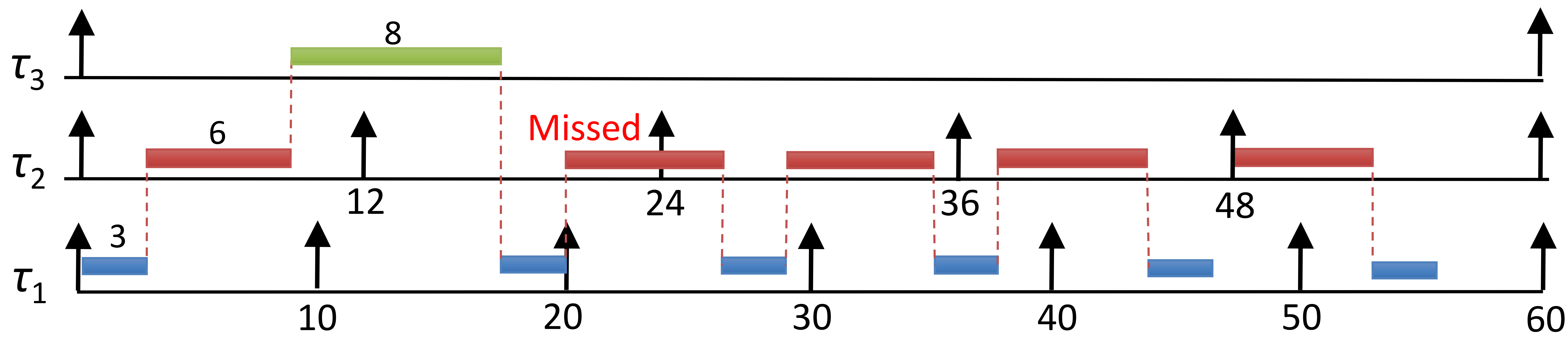
FIFO can actually achieve excellent schedulability!

[**periodic non-preemptive tasks** on a **uniprocessor**]

INTUITION

THE PROBLEM WITH PLAIN FIFO SCHEDULING

FIFO schedule of 3 periodic tasks:



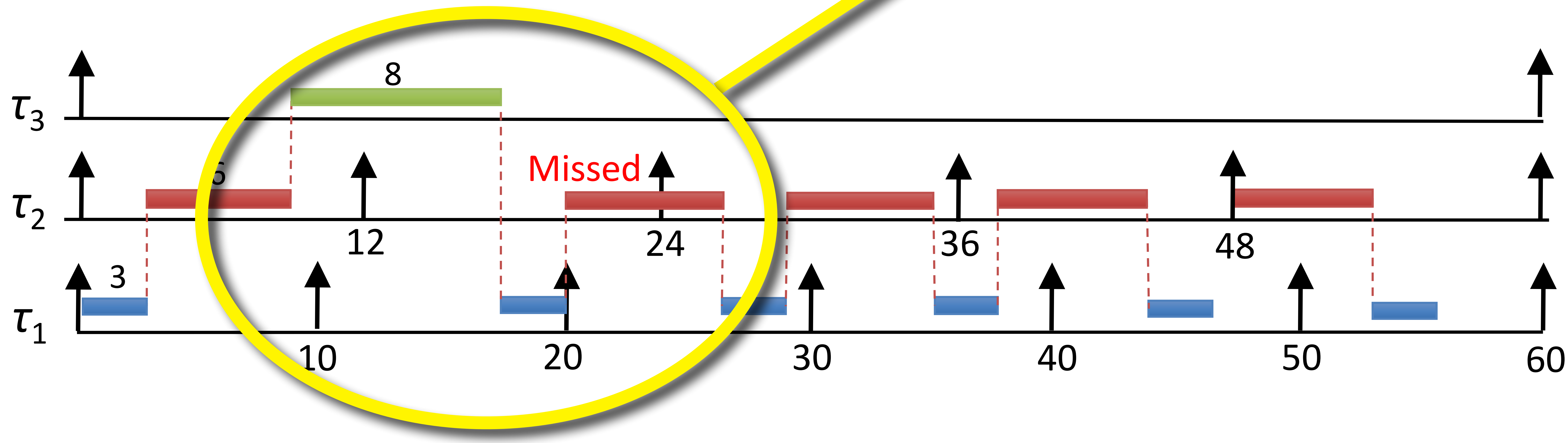
Task	WCET	Period
τ_3	8	60
τ_2	6	12
τ_1	3	10

THE PROBLEM

Plain FIFO is oblivious to deadlines and priorities

***τ_3* comes first → deadline miss**

FIFO schedule of 3 periodic tasks:



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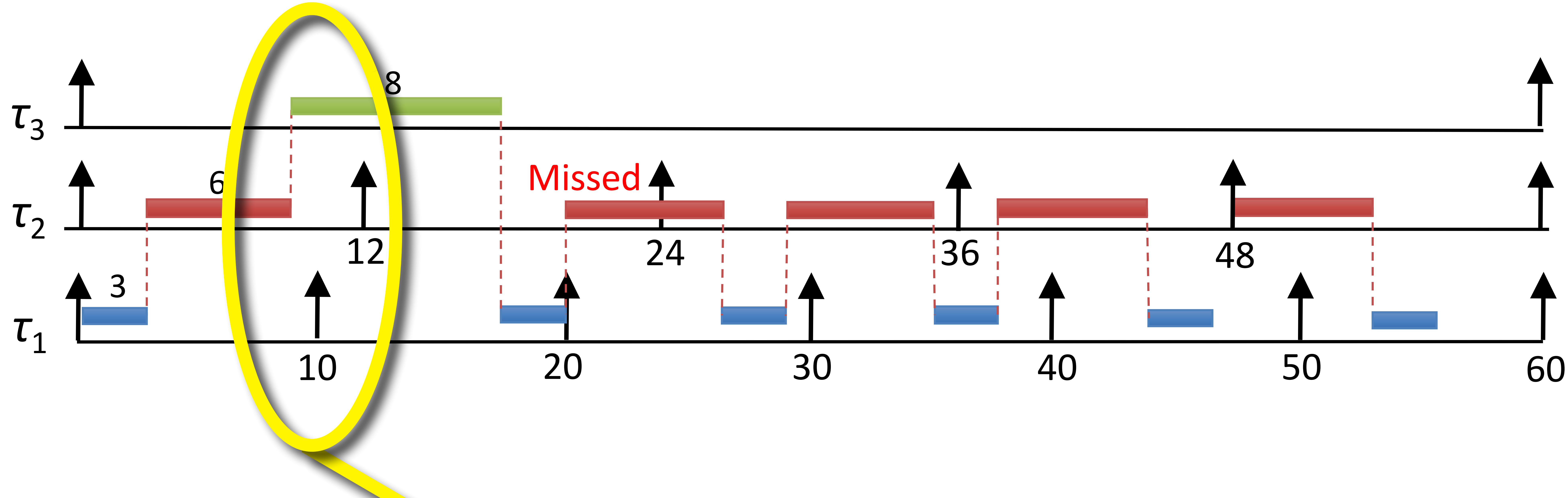


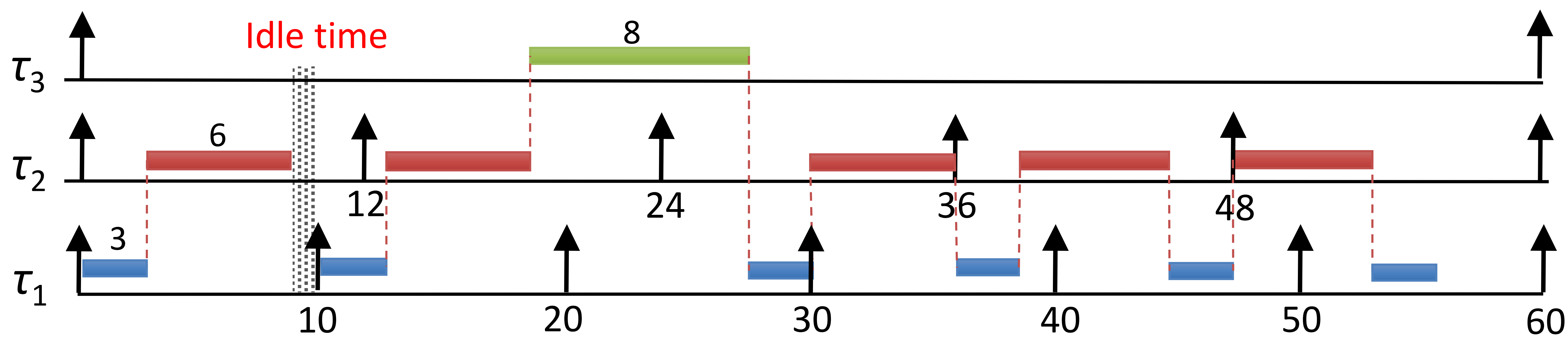
In fact, *any work-conserving policy* (EDF, RM, …)

must schedule τ_3 here → deadline miss.

NON-WORK-CONSERVING SCHEDULING

[*critical-window EDF: Nasri & Fohler, 2016*]

CW-EDF schedule of the same 3 periodic tasks:



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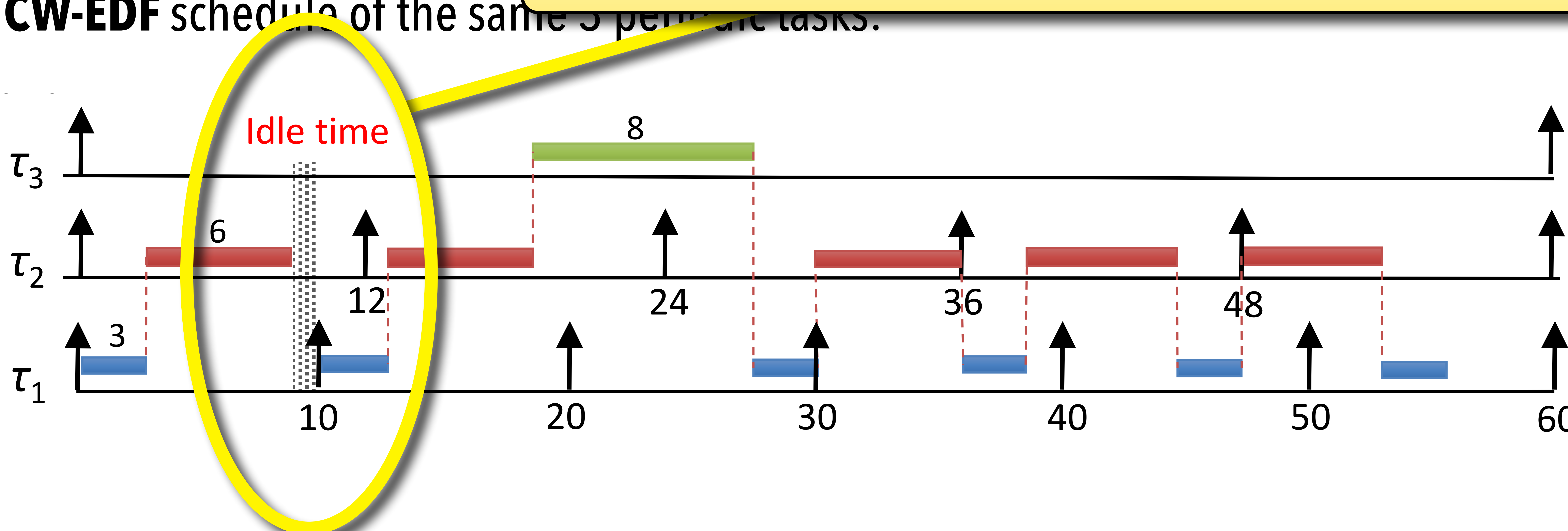
NON-WORK

[critical-window EDF: Nasri &

CW-EDF considers *future job arrivals* in the "critical window" and postpones τ_3 until later.

CW-EDF schedule of the same 3 periodic tasks.



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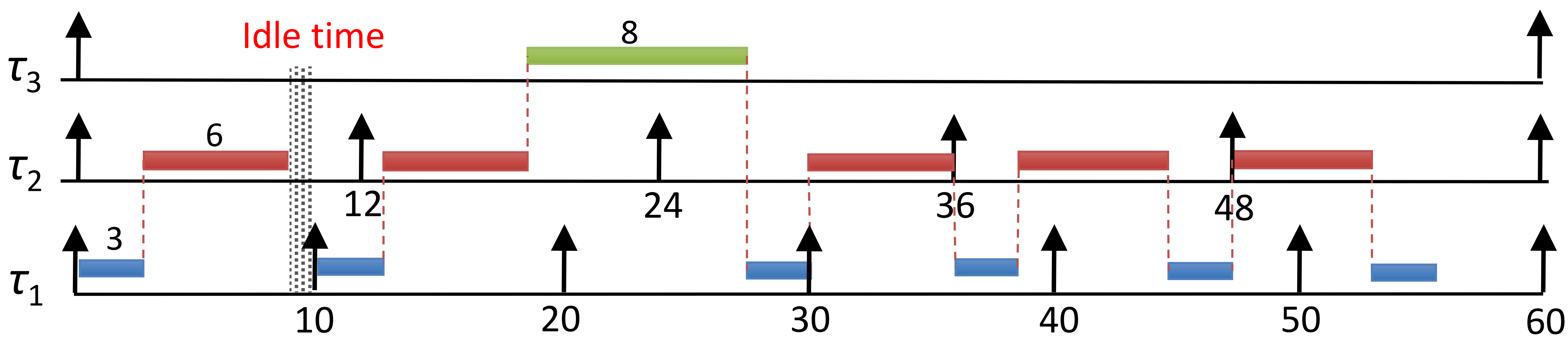


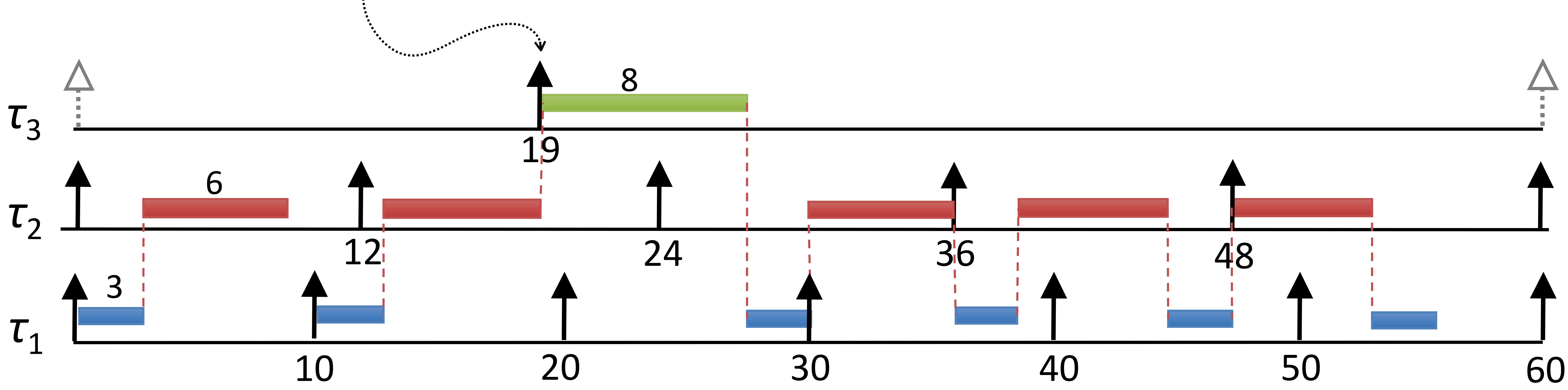
LIMITATION

CW-EDF incurs ***much higher runtime overheads*** than simple work-conserving policies.

ATMega2560 @ 16 MHz: ***9.2× higher than RM!***

INTUITION: FIFO + "JUST THE RIGHT" OFFSETS

FIFO schedule + *offset for* τ_3 :



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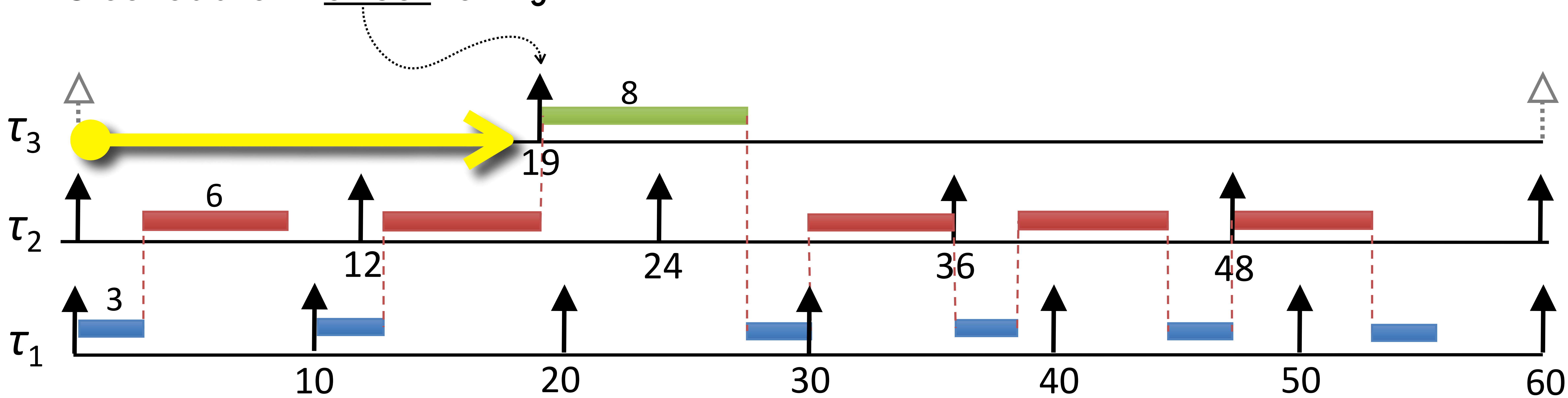
FIFO schedule + *offset for τ_3* :



Move τ_3 "out of the way" by *introducing* (or *adjusting*) a *release offset*.

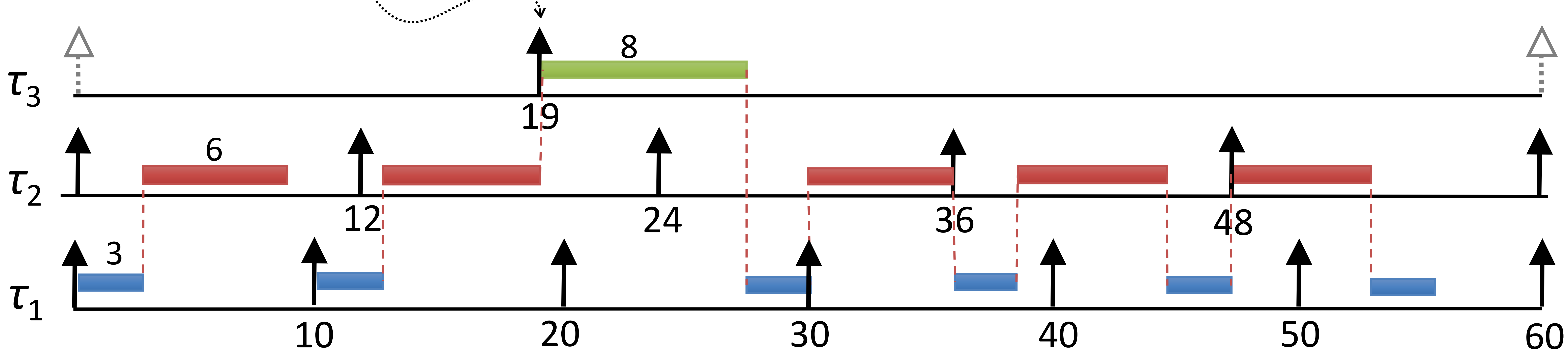
FIFO schedule becomes identical to CW-EDF schedule!

INTUITION: FIFO + "JUST THE RIGHT" OFFSETS

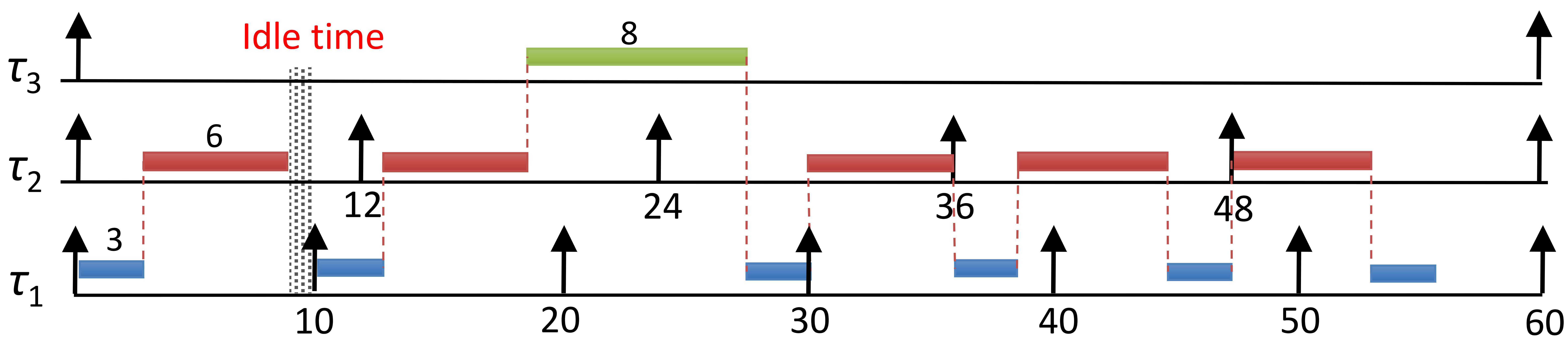
???

[Altmeyer, Sundharam, & Navet, 2016]

FIFO schedule + *offset for τ_3* :



CW-EDF schedule is identical:



<u>THIS PAPER</u>

OFFSET TUNING ALGORITHM

PROBLEM STATEMENT

Given a set of ***n*** *periodic non-preemptive tasks*,
find, for each job of each task, a ***release offset*** such that

(A) the resulting ***FIFO schedule is feasible***, and

(B) the ***number of offsets*** per task is ***minimized***.

Challenges

- ➡ space of possible offsets is large and unstructured
- ➡ even ignoring (B), solving "just" (A) is *very* difficult

Altmeyer et al.

- ➡ randomize offsets + test
- ➡ not systematic
- ➡ scalability limitations

[*S. Altmeyer, S. Sundharam, and N. Navet, "The case for FIFO real-time scheduling," University of Luxembourg, Tech. Rep., 2016*]

KEY INSIGHT

Given a set of ***n*** *periodic non-preemptive tasks*,
find, for each job of each task, a ***release offset*** such that

(A) the resulting ***FIFO schedule is feasible***, and

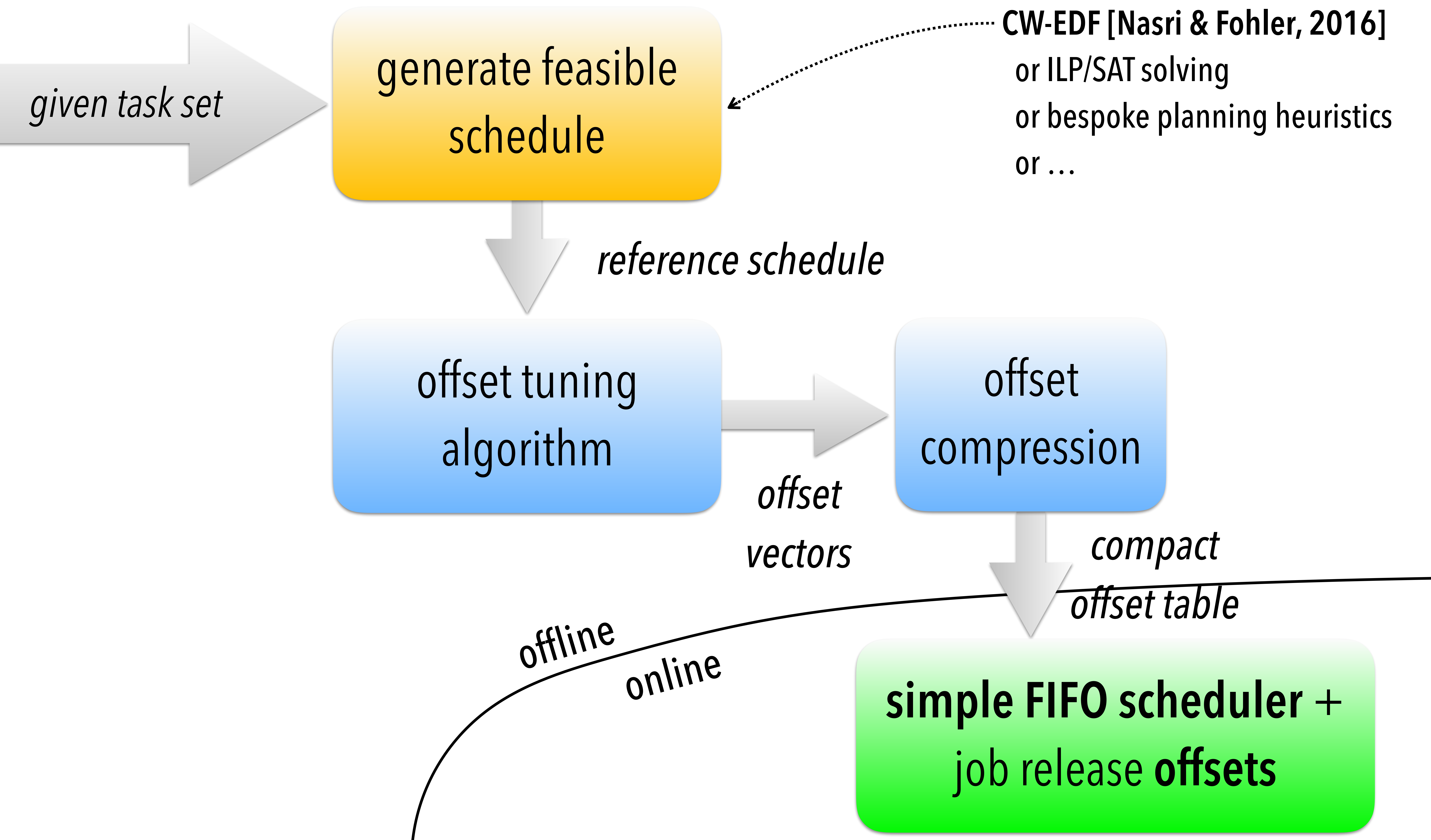
(B) the ***number of offsets*** per task is ***minimized***.

Solving (A) is very difficult… so we don't!

OFFSET TUNING

Infer offsets *from a given* ***feasible reference schedule****, while greedily working towards (B).*

OFFSET TUNING – OVERVIEW



SCHEDULE EQUIVALENCY

A schedule S_1 is equivalent to S_2 if

(i) they schedule the ***same jobs***,

(ii) in the ***same order***, and

(iii) ***jobs start no later*** in S_1 than in S_2.

Non-preemptive execution

➡ jobs also complete no later in S_1 than in S_2

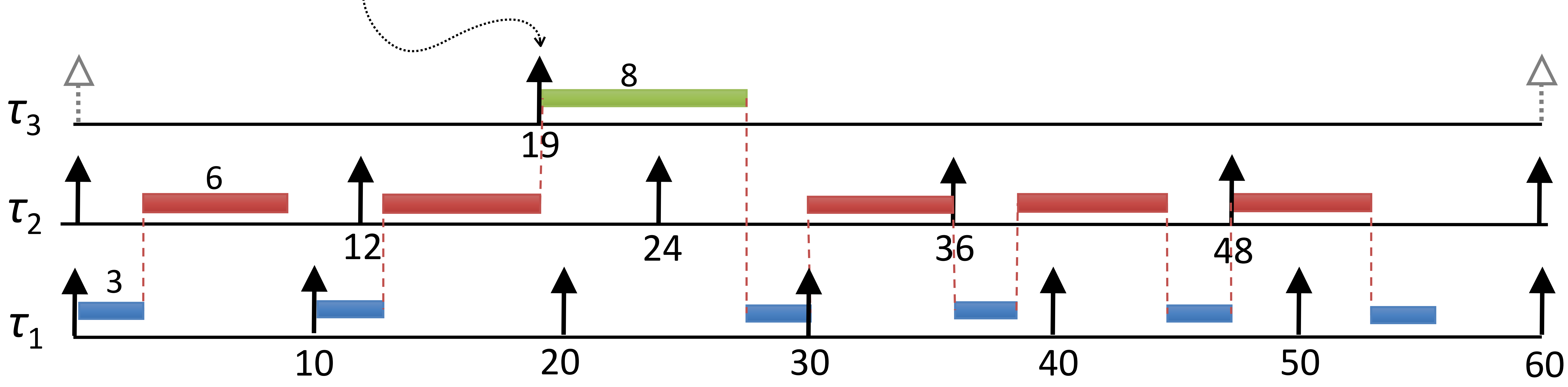
Offset Tuning

➡ ensures FIFO schedule is equivalent to reference schedule

POI: POTENTIAL OFFSETS INTERVAL

POI of a job: range of release offsets that ***guarantee schedule equivalency***.

FIFO schedule + ***<u>offset</u> for τ_3*** :

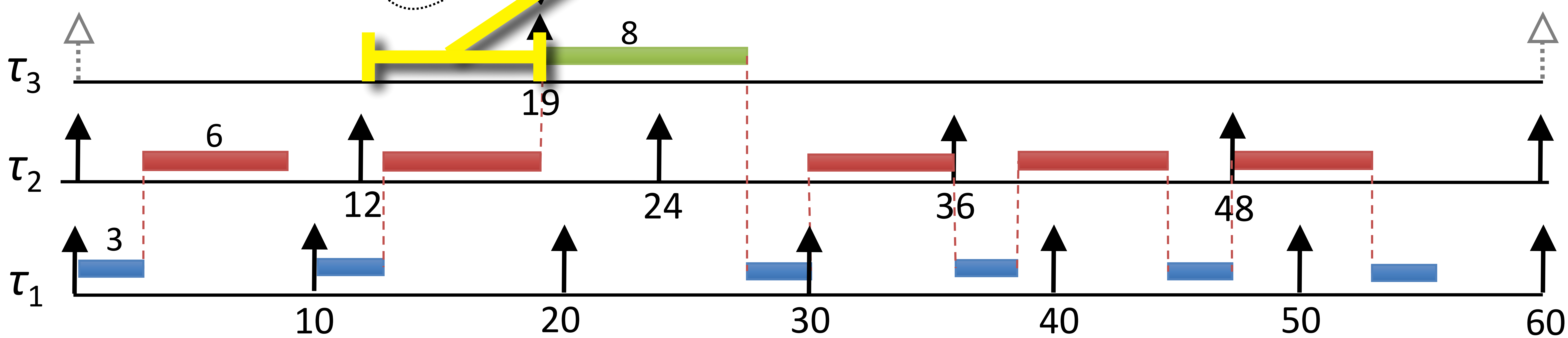


POI: POTENTIAL OFFSETS INTERVAL

POI of a job: range of release offsets that ***guarantee schedule equivalency***.

POI: any release time of τ_3 in (12, 19] will yield an equivalent schedule.

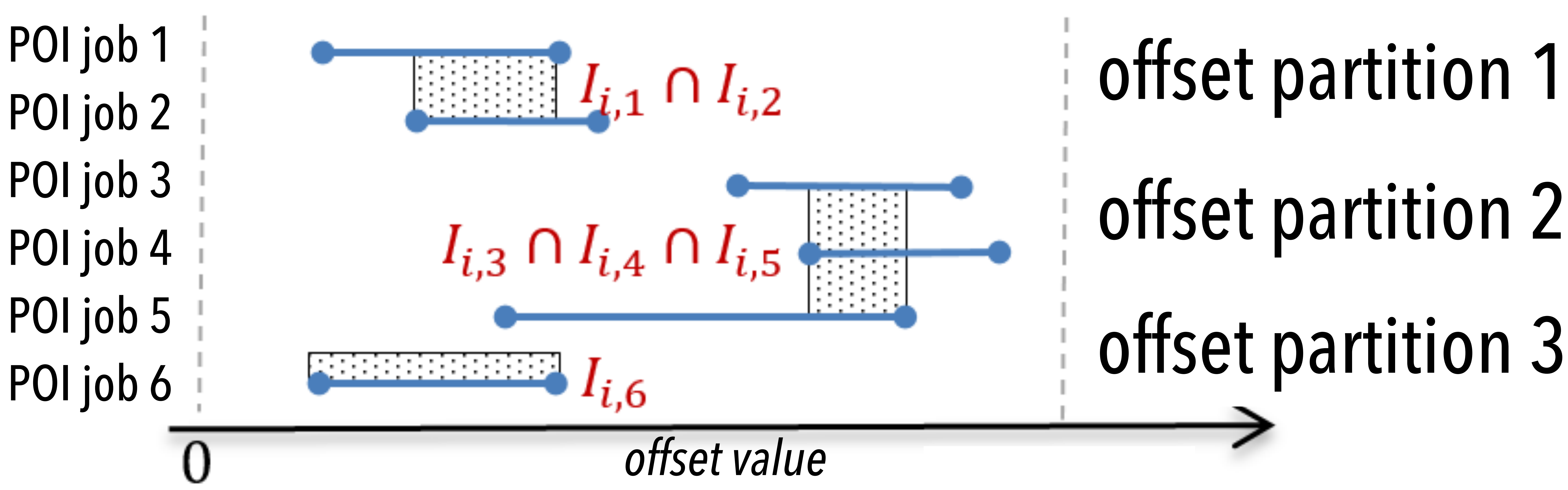
FIFO schedule + *offset for τ_3* :



OFFSET PARTITION

Consecutive jobs of a task form an **offset partition** if they have ***mutually intersecting POIs***.

➔ *can be assigned a single offset*



➔ *offset partitioning not necessarily unique*

OFFSET TUNING ALGORITHM (*SIMPLIFIED*)

for each task τ_i in deadline-monotonic order:

greedily create ***offset partitions*** for τ_i

assuming ***jobs of larger-deadline tasks***
are released as in reference schedule

Need to start somewhere…

shorter relative deadline = fewer options

for each task τ_i in deadline-monotonic order:

greedily create ***offset partitions*** for τ_i

assuming ***jobs of larger-deadline tasks***
are released as in reference schedule

Release times of not-yet-processed jobs still unknown → speculate.

Mis-speculation increases the number of offset partitions,

*but **does not** cause the algorithm to fail.*

PROPERTIES OF OFFSET TUNING

REFERENCE SCHEDULE EQUIVALENCY

*In the resulting FIFO schedule, **no job completes later** than in the original reference schedule.*

PER-TASK MINIMAL OFFSET PARTITIONS

The greedy offset partitioning strategy yields a minimal number of offset partitions (for a given task).

NON-MINIMAL OFFSET PARTITIONS FOR ENTIRE TASK SET

*Deadline-monotonic processing order does not guarantee overall minimal number of offset partitions (but **works well empirically**).*

SINGLE-OFFSET HEURISTICS

What if we want just a *single offset* per task?

➡ no extra memory required

➡ compatibility with existing systems

FST: First-Start-Time Heuristic

➡ pick start time of first job in reference schedule

FOP: First-Offset-Partition Heuristic

➡ pick offset from first offset partition of the task

EVALUATION

EVALUATION QUESTIONS

Q1: Does FIFO + Offset Tuning still have low runtime overheads?

Q2: Does FIFO + Offset Tuning (FIFO-OT) significantly improve schedulability relative to EDF/RM?

Q3: How many offsets are assigned?

Q4: How much memory is needed?

PROTOTYPE PLATFORM

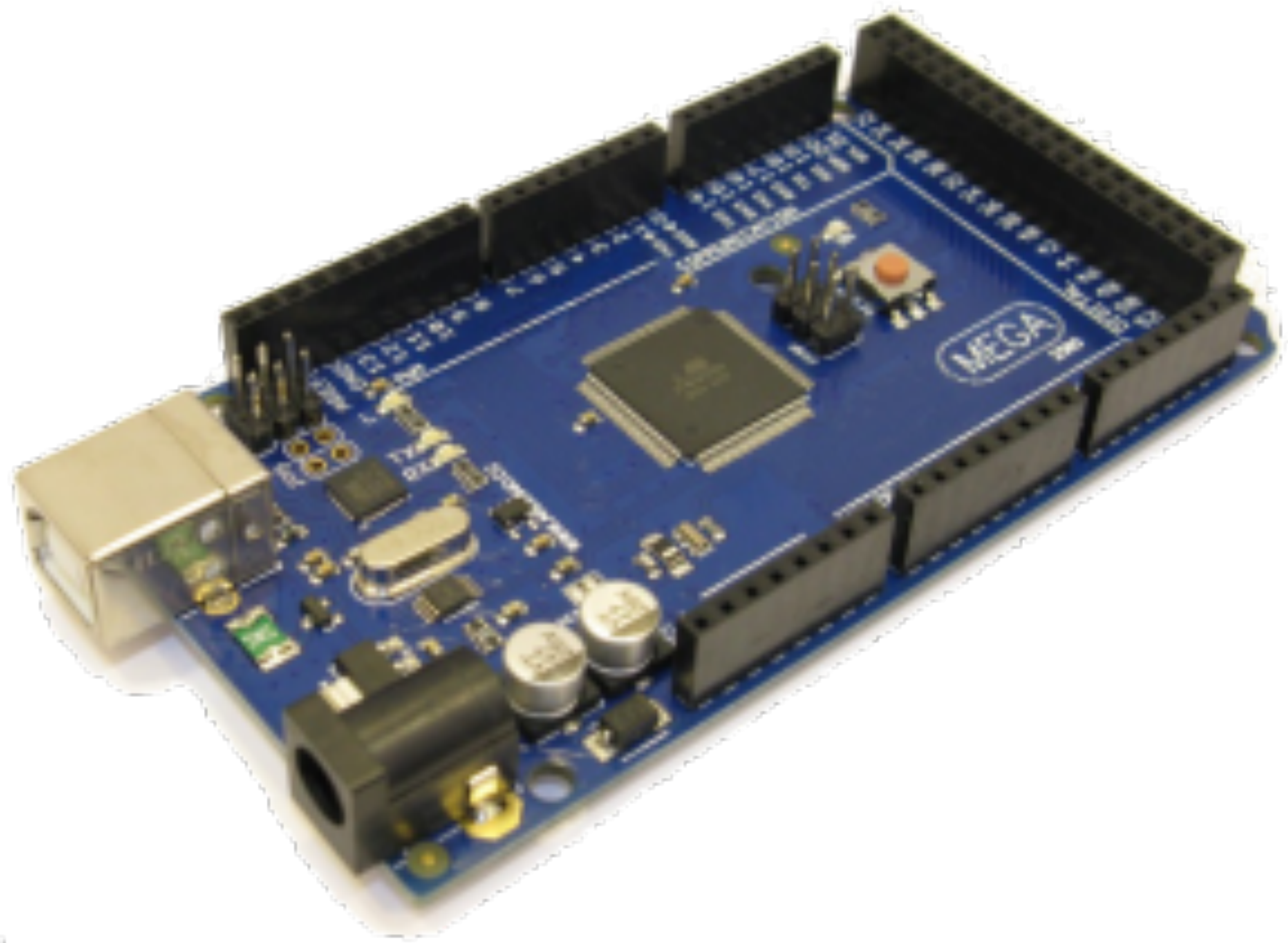
Arduino Mega 2560

ATMega2560 microcontroller

16 MHz CPU

256 KiB Flash

8 KiB SRAM (no cache)



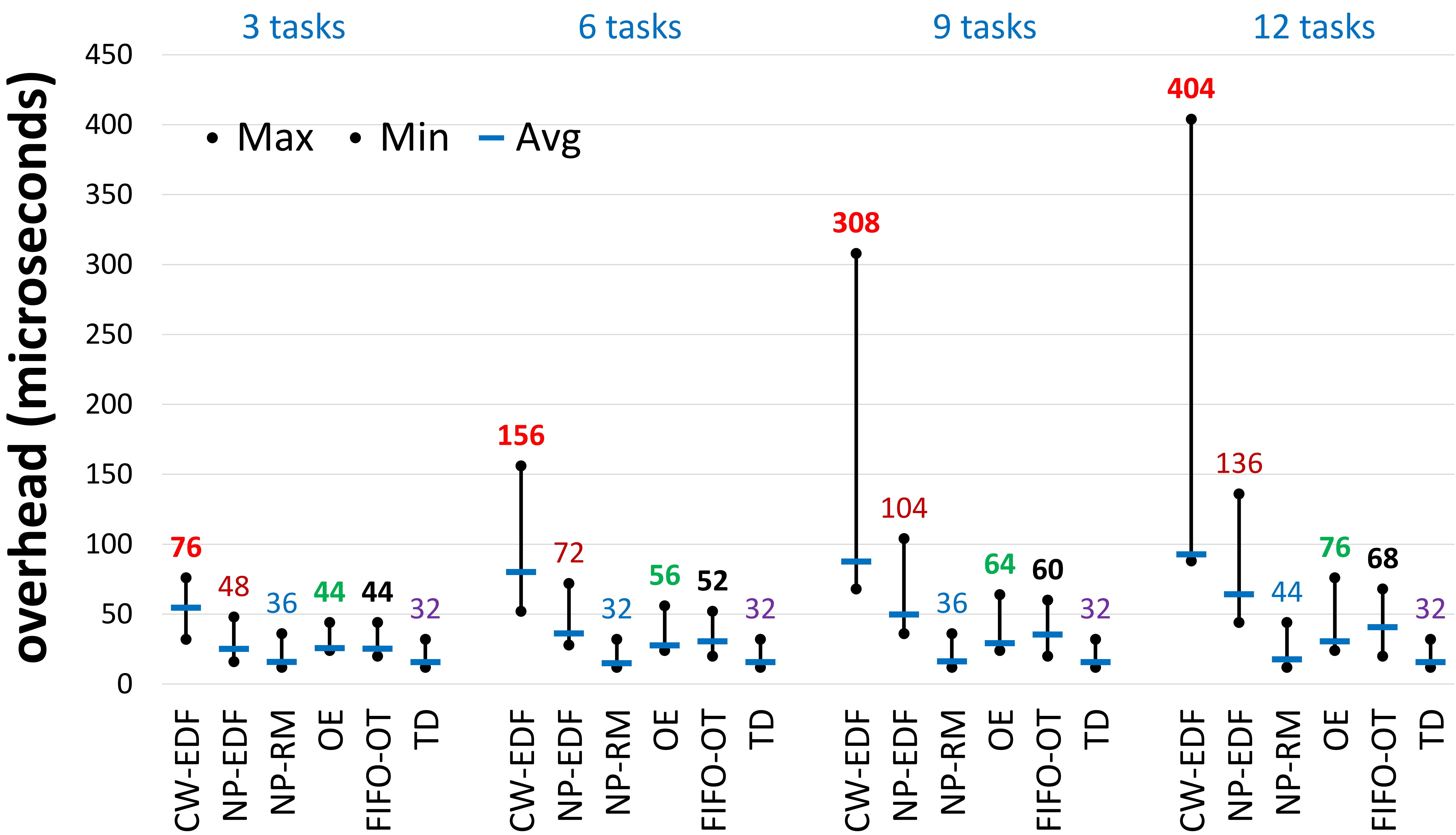
gcc: -Os

http://people.mpi-sws.org/~bbb/papers/details/rtas18

EVALUATED SCHEDULERS

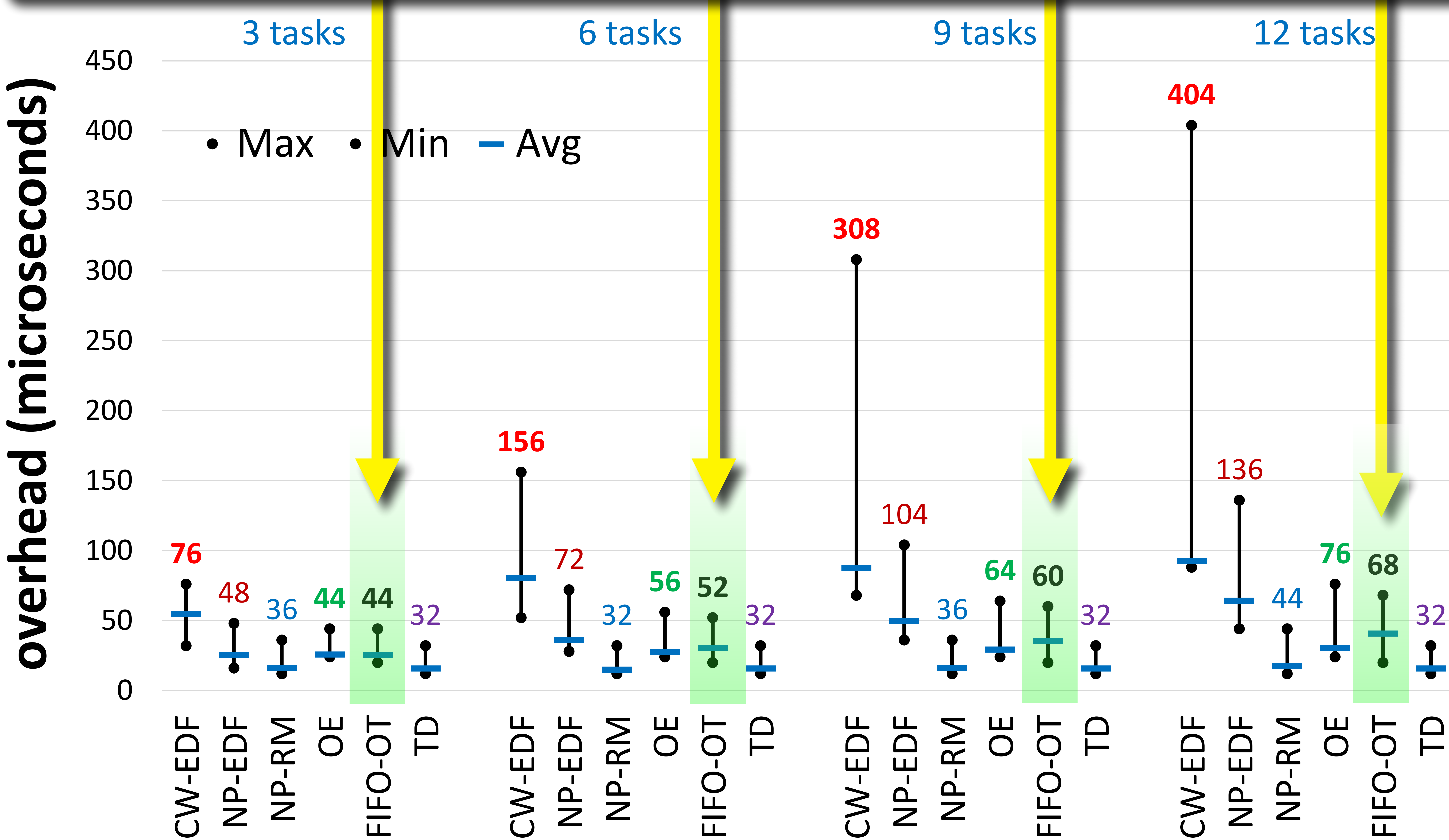
NP-RM	plain non-preemptive rate-monotonic scheduling
NP-EDF	plain non-preemptive EDF
CW-EDF	Critical Window EDF [*Nasri & Fohler, 2016*]
TD	Table-driven (a.k.a. static or time-triggered) scheduling
OE	Offline Equivalence [*Nasri & Brandenburg, 2017*]
FIFO-OT	FIFO + Offset Tuning [*this paper*]

Q1: RUNTIME OVERHEADS



LOW RUNTIME OVERHEADS

FIFO-OT is much cheaper than CW-EDF and roughly similar to NP-RM and OE.



WORKLOADS

based on

Kramer, Ziegenbein, and Hamann, "*Real world automotive benchmark for free,*" WATERS 2015

BOSCH

Periods

➡ non-uniformly in {1, 2, 5, 10, 20, 50, 100, 200, 1000} milliseconds

Runnable BCETs and WCETs

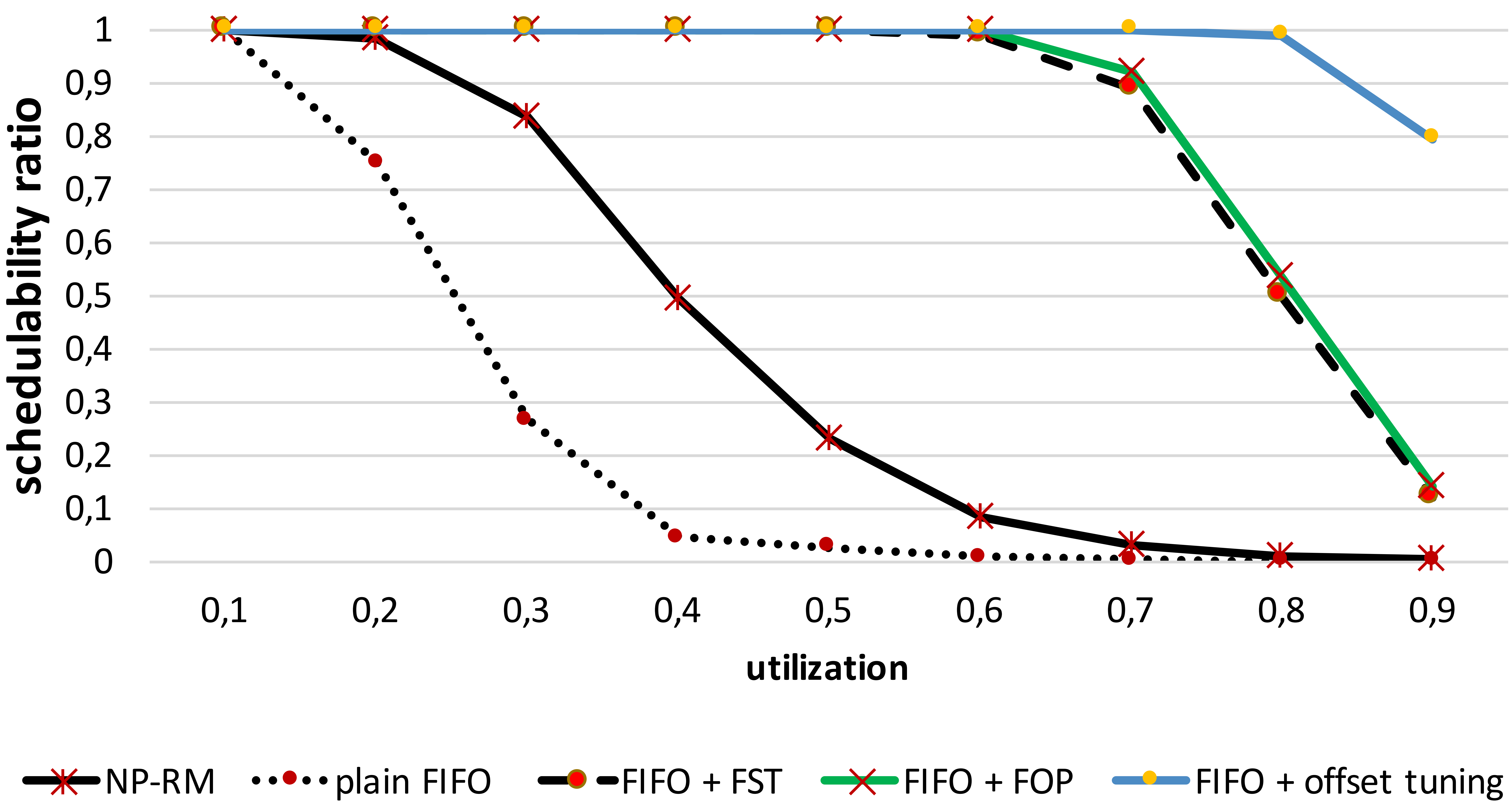
➡ randomly generated based on statistics provided by Kramer et al.

Runnable Packing

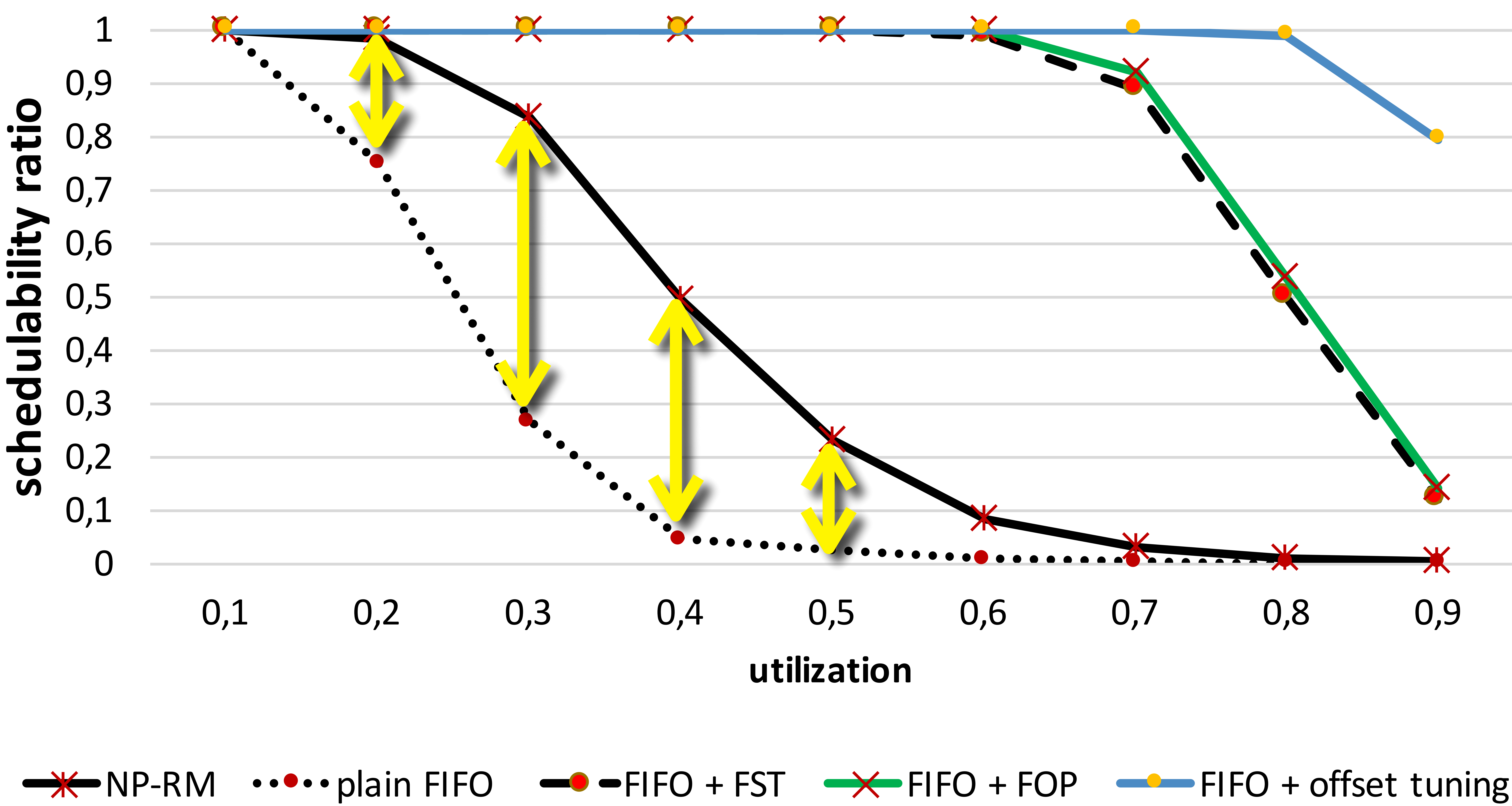
➡ Runnables aggregated into tasks until random utilization threshold reached

➡ *utilization threshold ensures feasibility under non-preemptive scheduling*

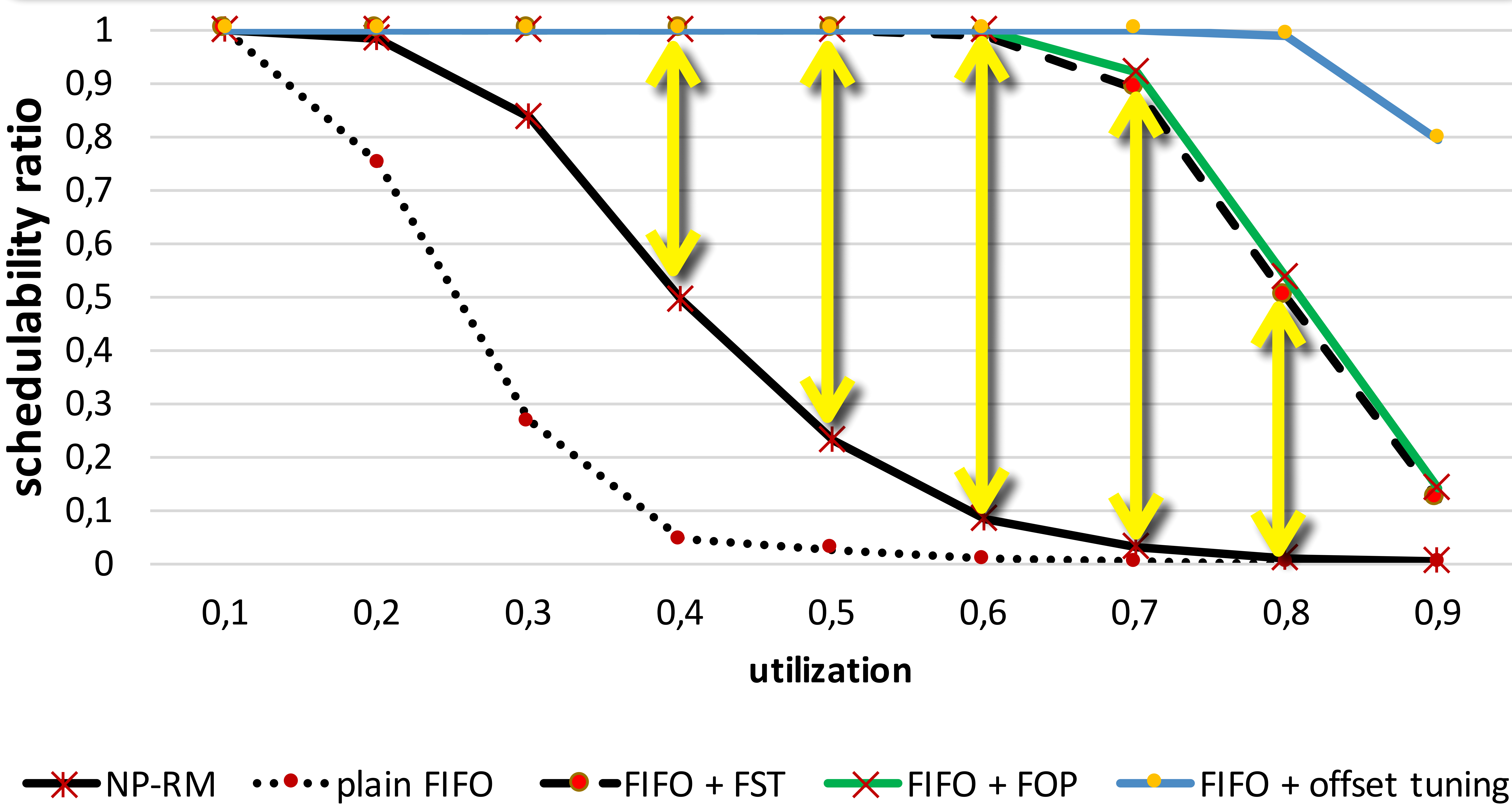
Q2: SCHEDULABILITY GAINS



As expected, plain FIFO exhibits very low schedulability.



Assigning even a *single offset* per task can substantially increase schedulability!



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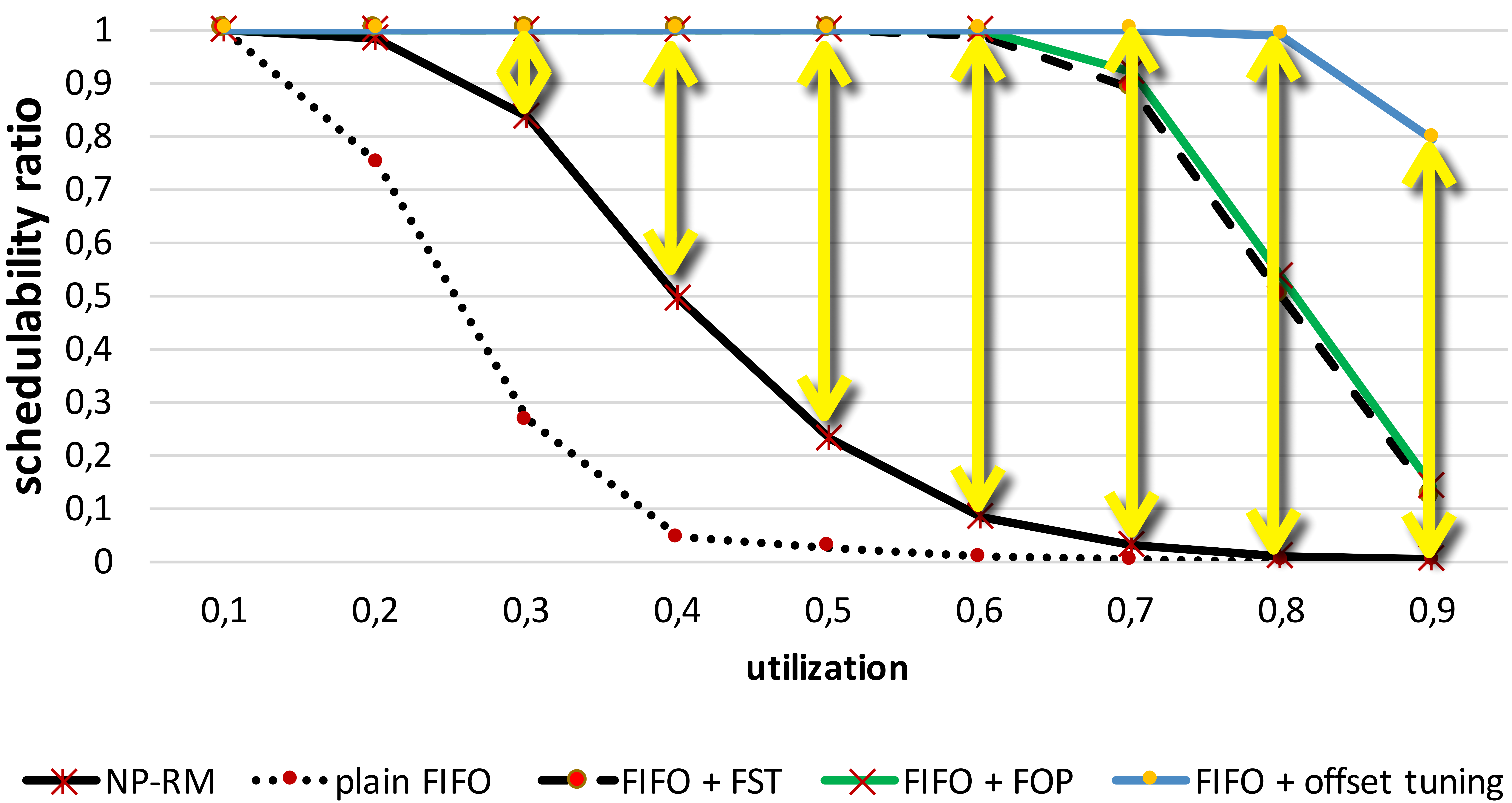
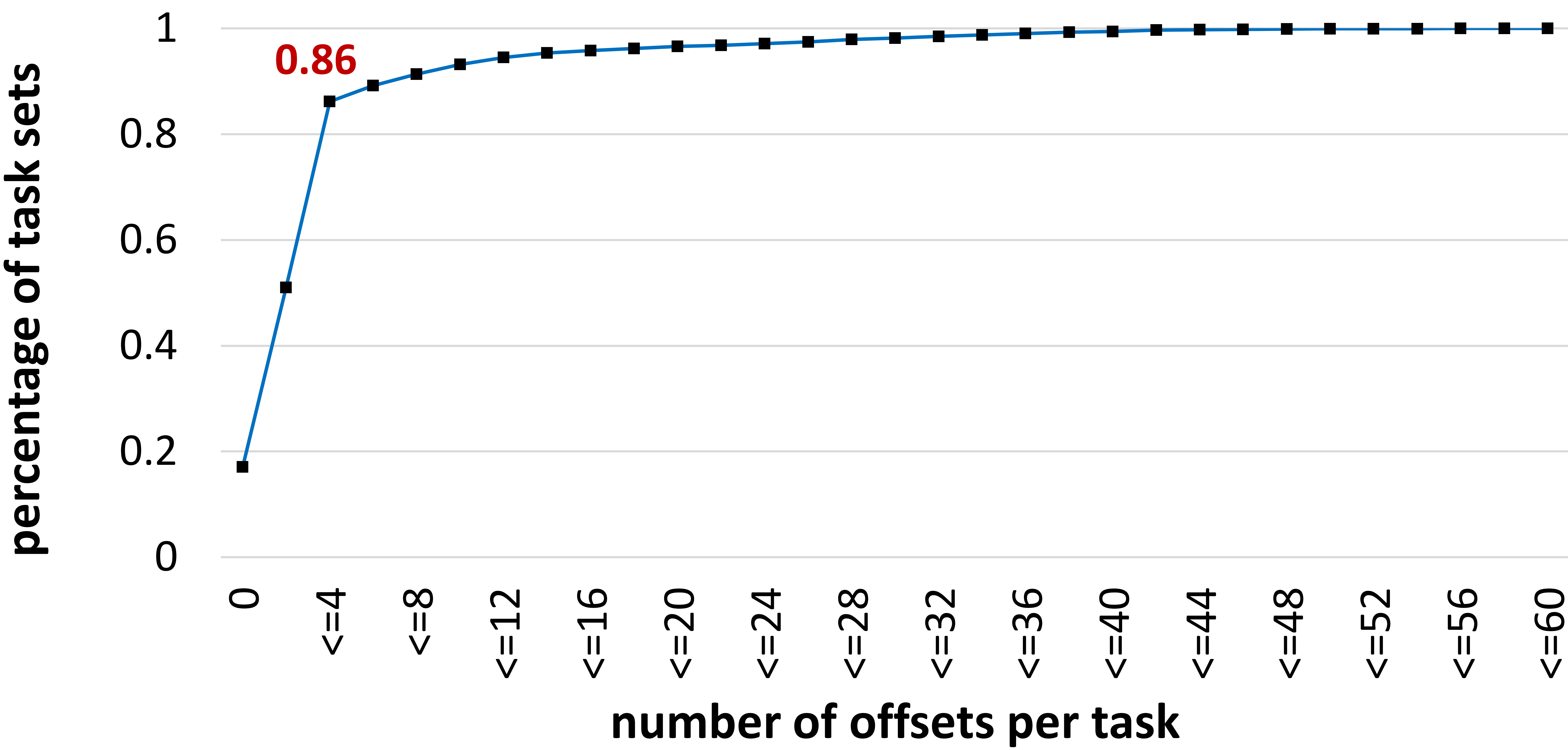


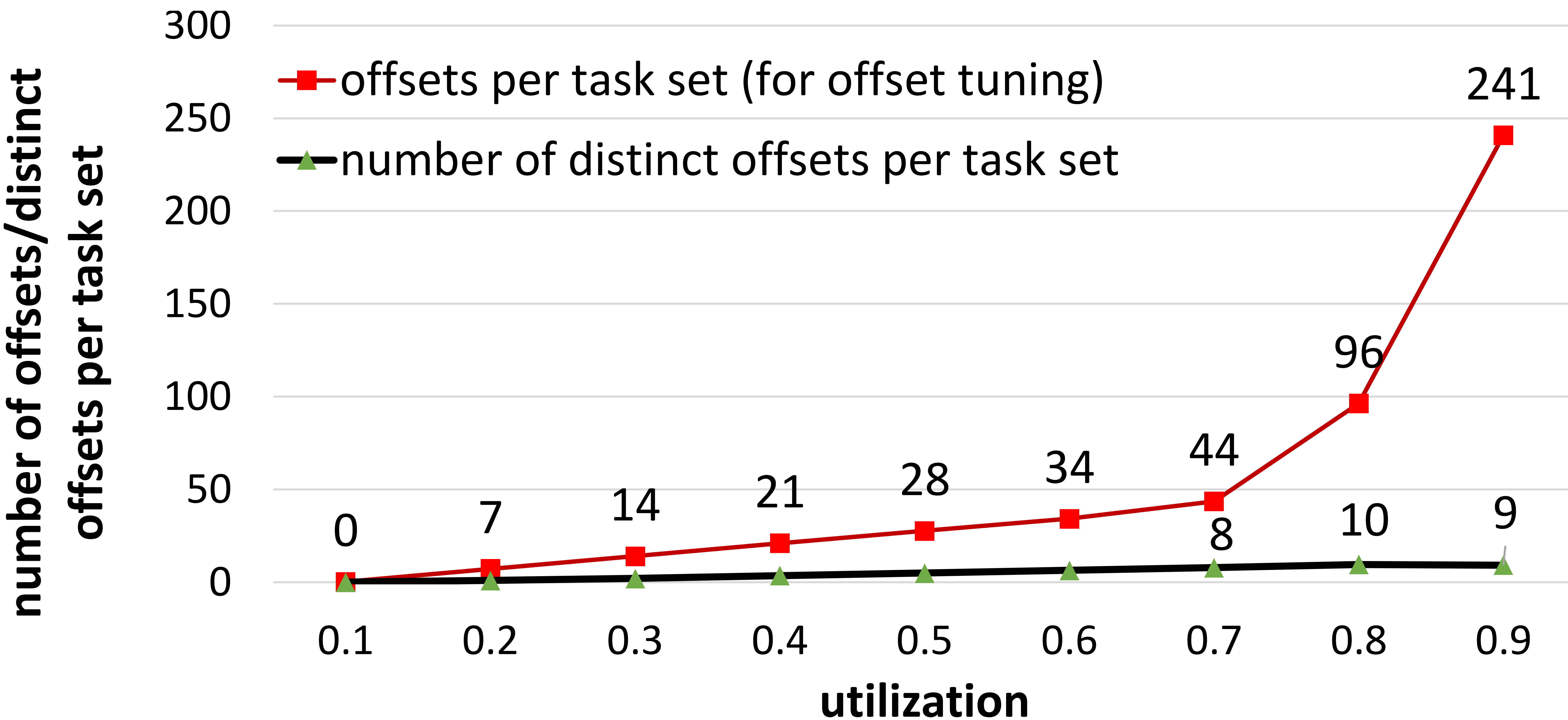
FIFO-OT achieves *much higher schedulability*, thanks to CW-EDF reference schedule.

Q3: NUMBERS OF OFFSETS PER TASK



➔ *Most tasks require only few offset partitions.*

NUMBERS OF UNIQUE OFFSETS PER TASK SET

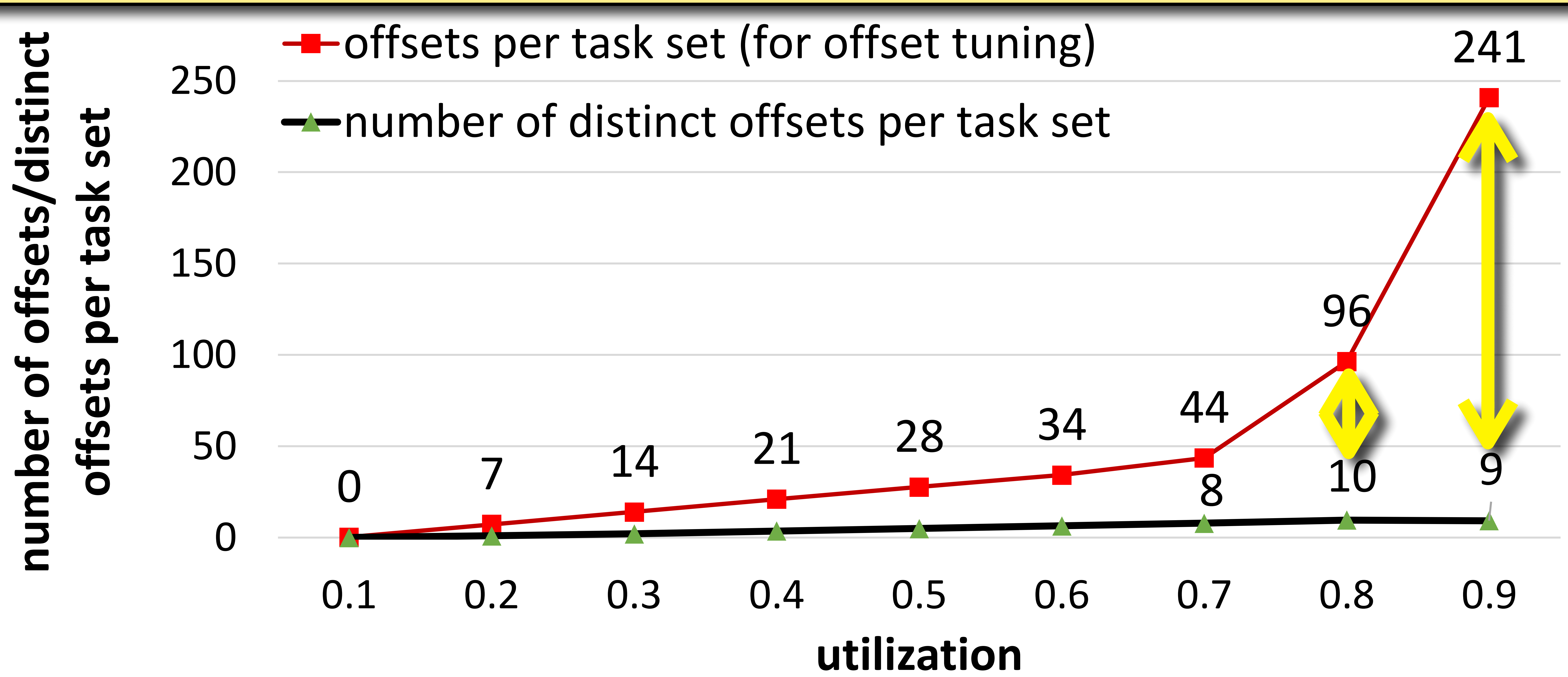


*Across the hyper-period, **offsets values repeat cyclicly**.*

➔ *Opportunity to store offsets efficiently (compression).*

NUMBERS OF UNIQUE OFFSETS PER TASK SET

Up to 25× reduction in the number of offset values that must be stored.



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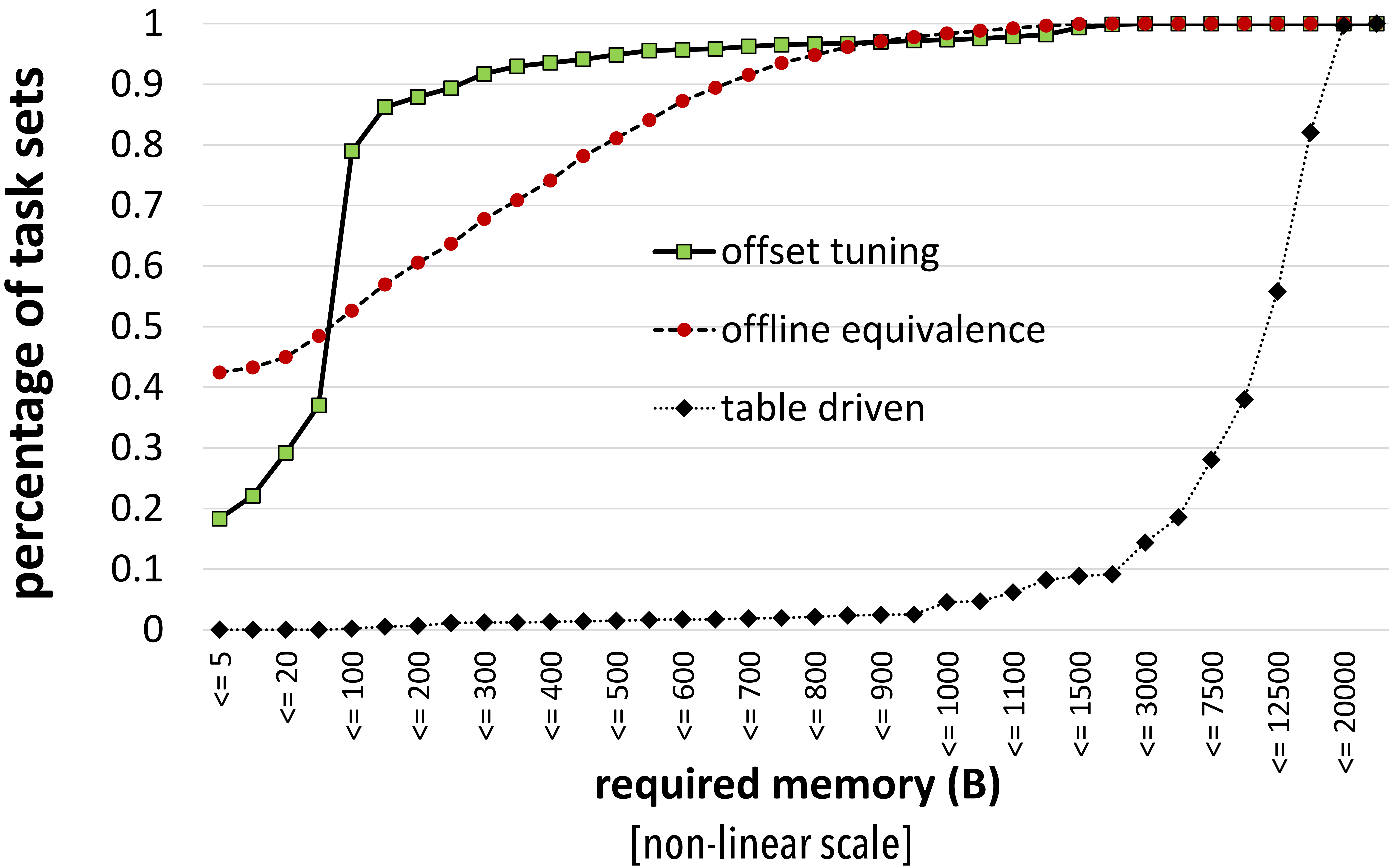
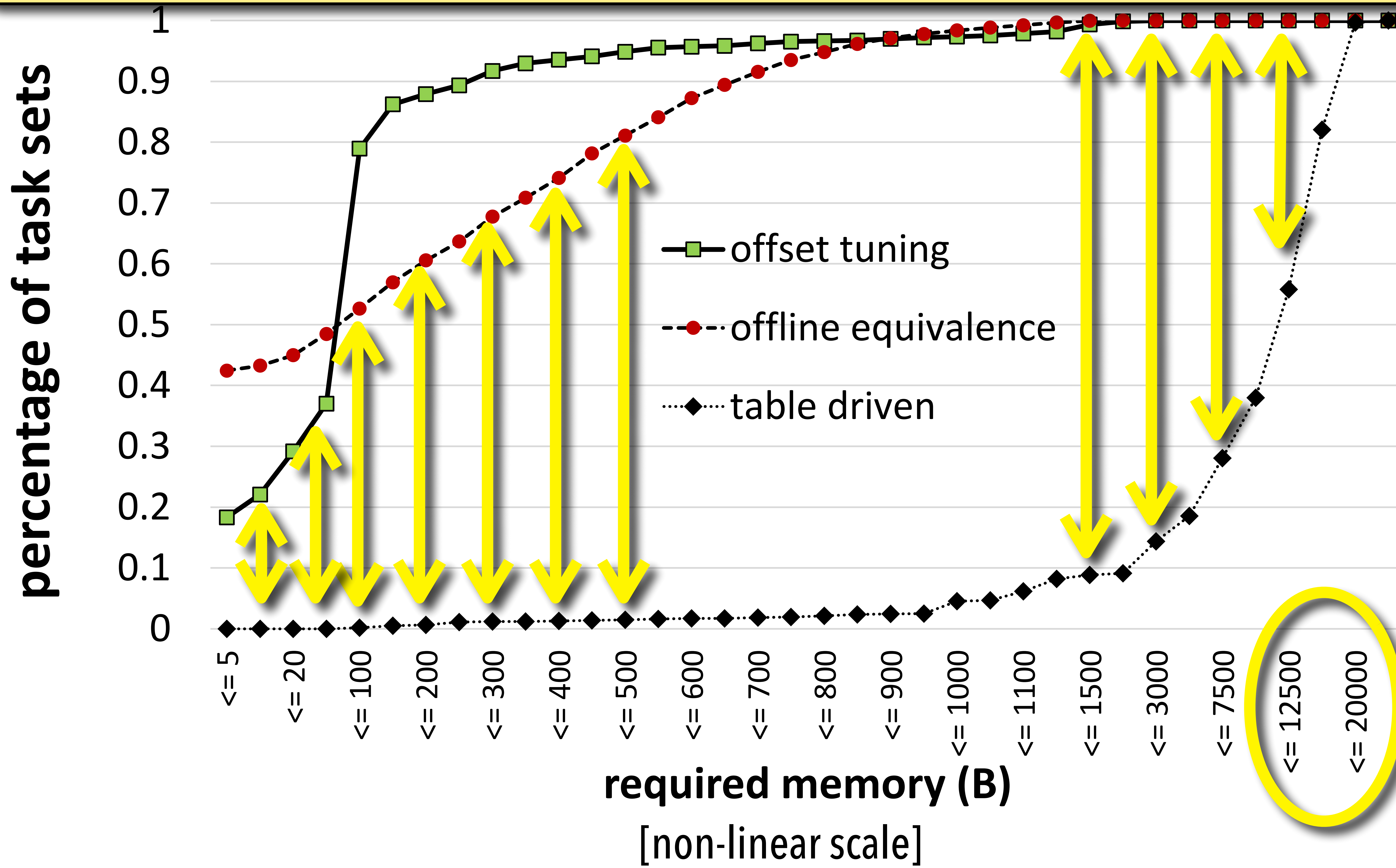
MEMORY USAGE



Both *OE and FIFO-OT require much less memory* than table-driven scheduling.

dozens to hundreds of bytes vs. 10KiB-20KiB



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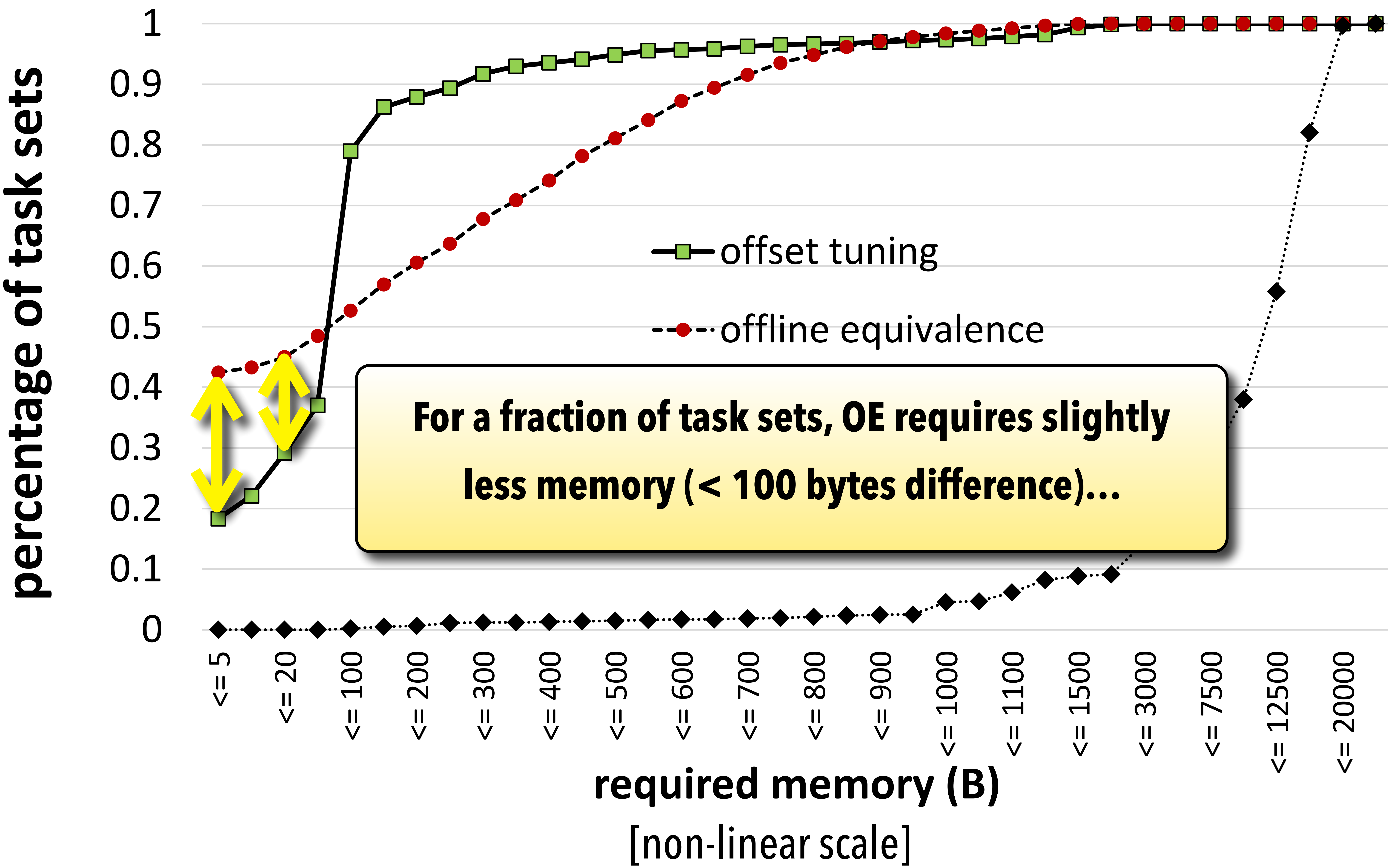
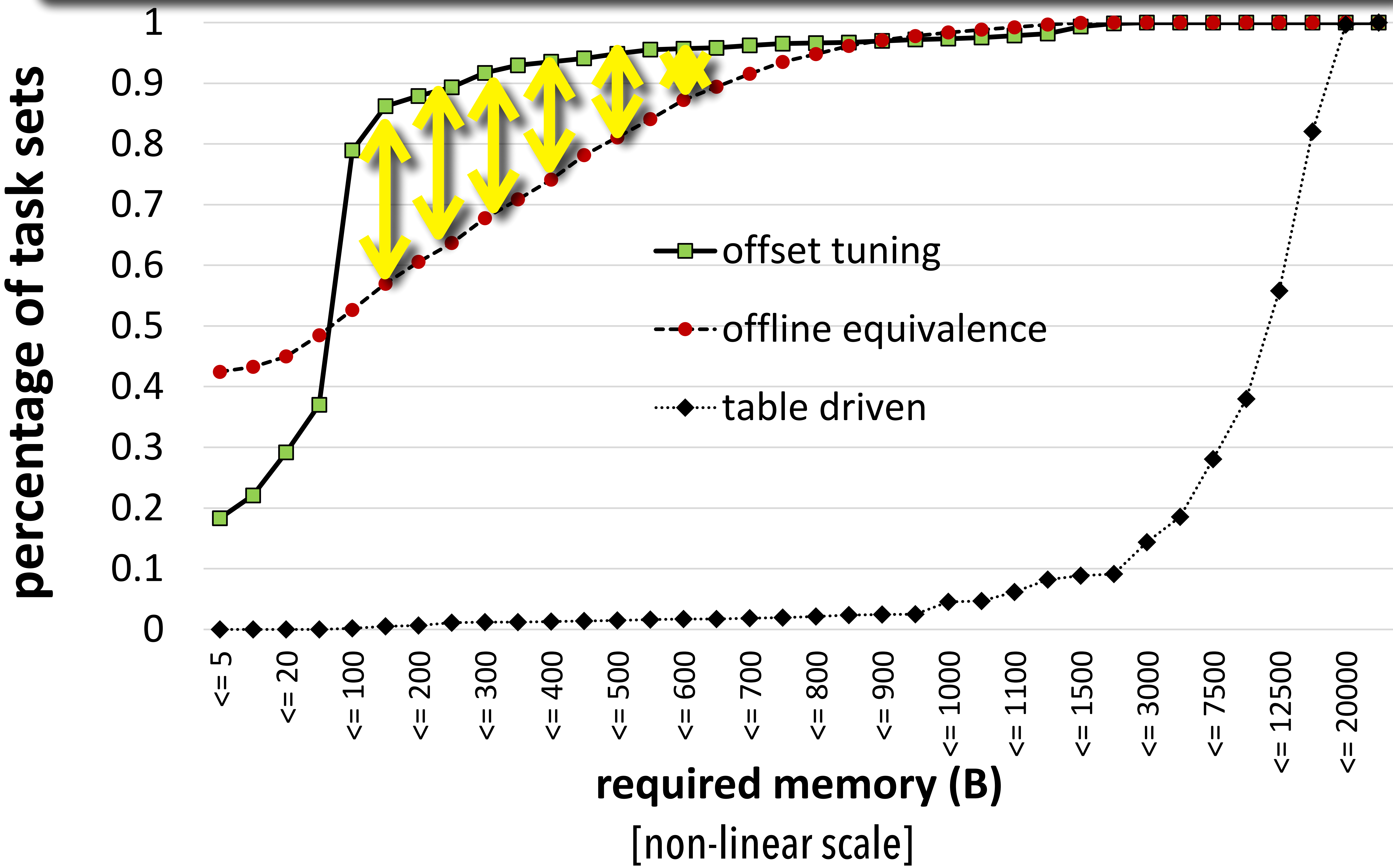
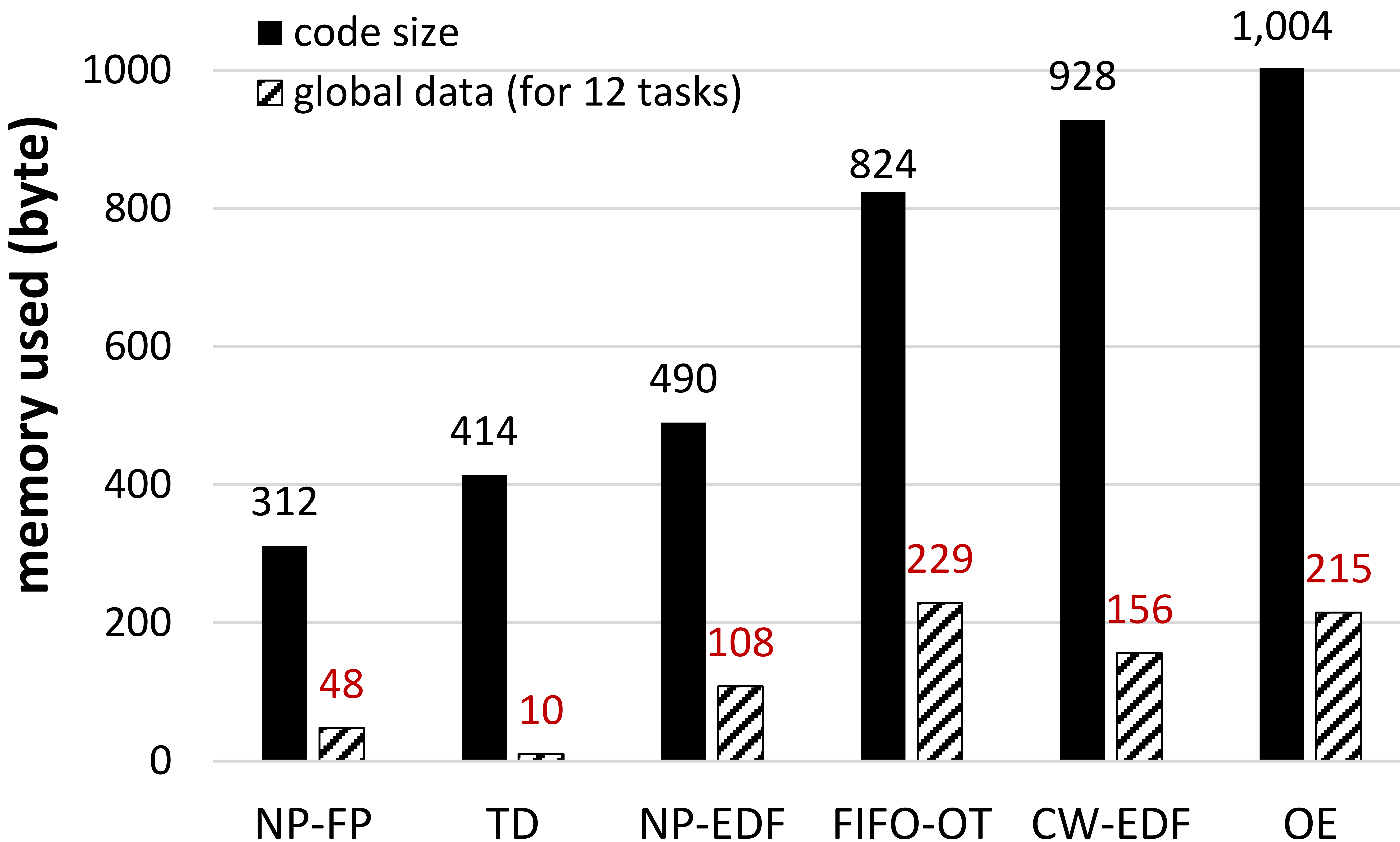


For a fraction of task sets, OE requires slightly less memory (< 100 bytes difference)…

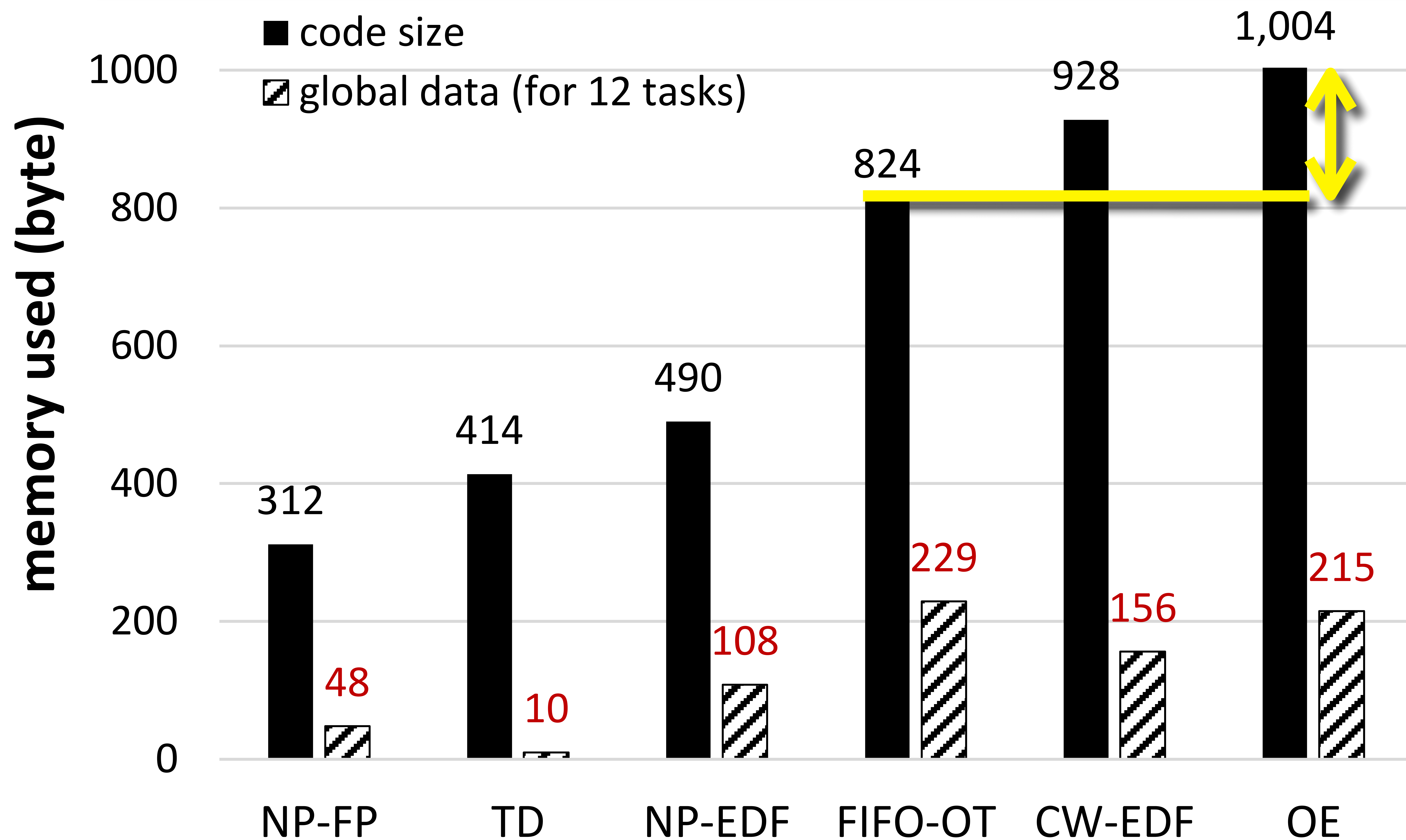
...but FIFO-OT can support over *90% of task sets with ≤ 250 bytes* of offset data.



IMPLEMENTATION FOOTPRINT



About 150 bytes *smaller footprint* than OE (RAM + code).



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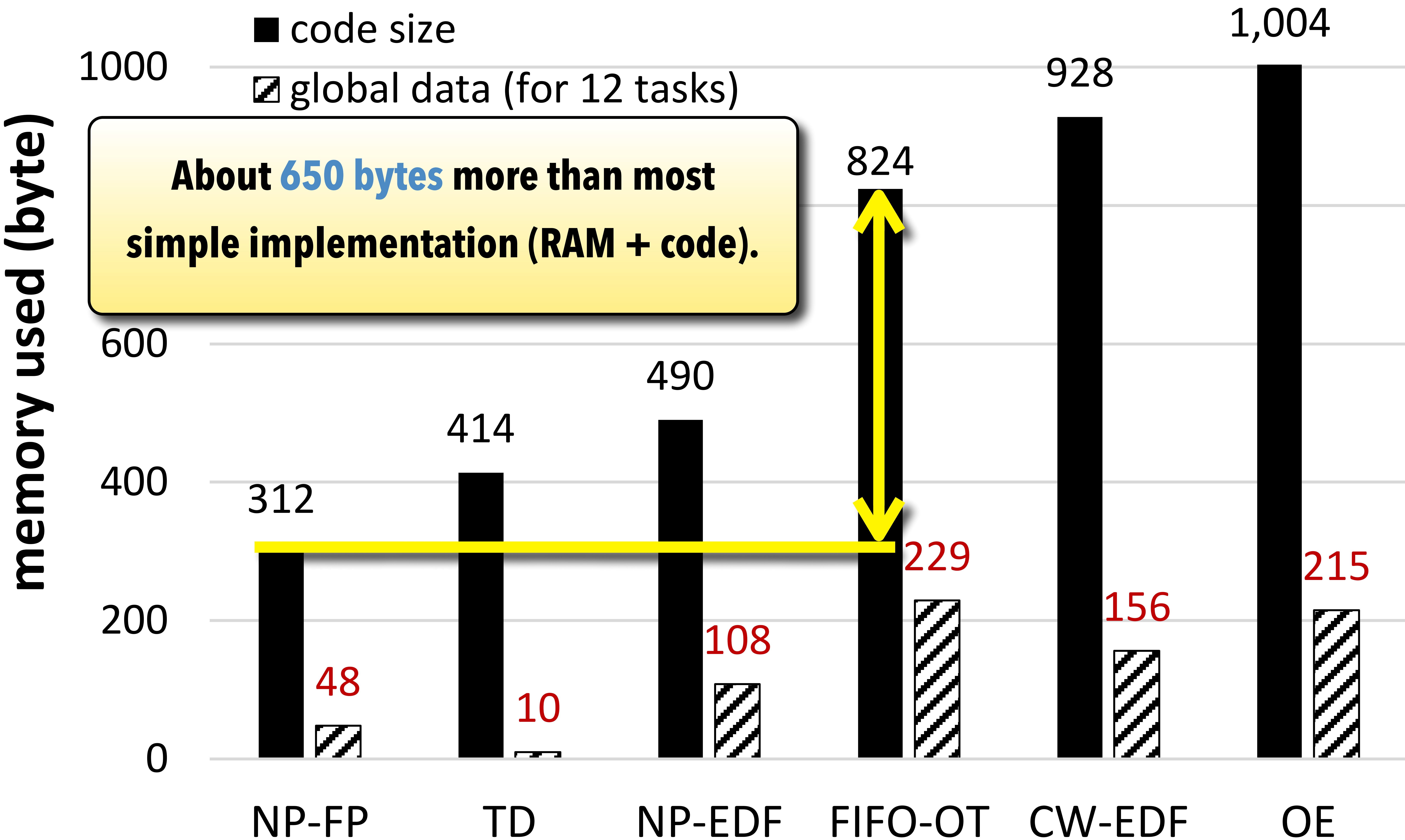

CONCLUSION

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OFFSET TUNING – OVERVIEW

given task set

generate feasible schedule

CW-EDF [Nasri & Fohler, 2016]
or ILP/SAT solving
or bespoke planning heuristics
or …

reference schedule

offset tuning algorithm

offset vectors

offset compression

compact offset table

offline

online

simple FIFO scheduler + job release **offsets**

PROPERTIES OF OFFSET TUNING

REFERENCE SCHEDULE EQUIVALENCY

In the resulting FIFO schedule, ***no job completes later*** *than in the original reference schedule.*

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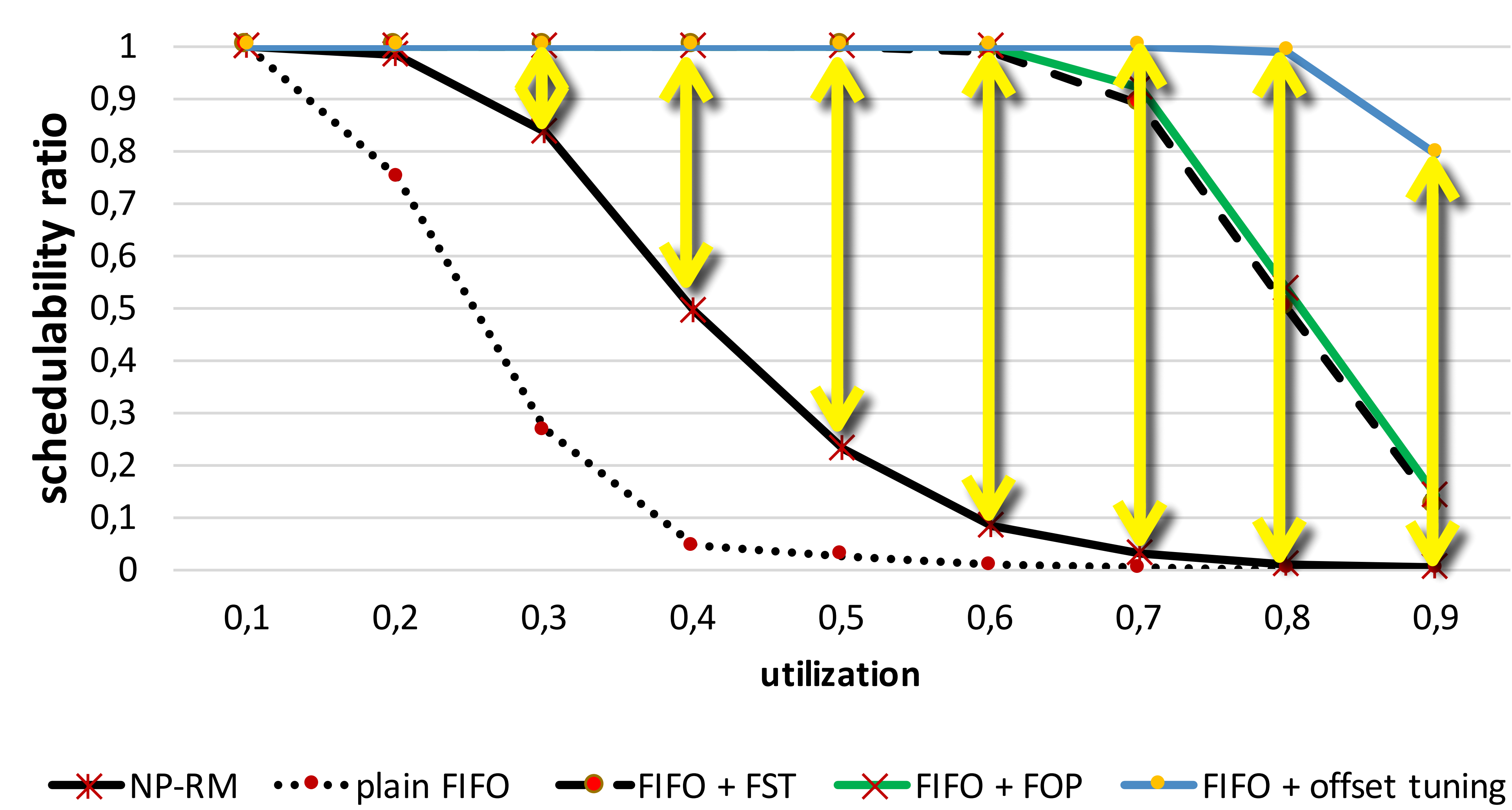


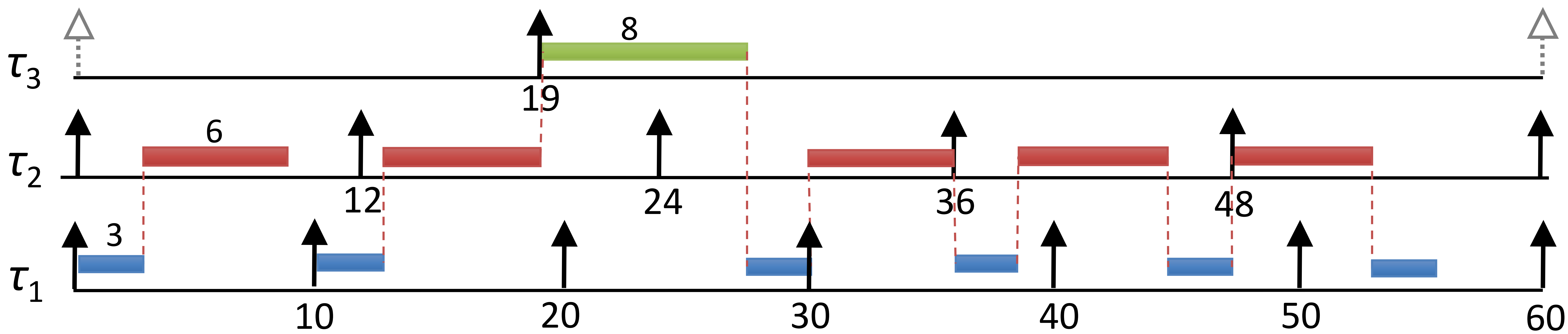
FIFO-OT achieves *much higher schedulability*, thanks to CW-EDF reference schedule.

APPENDIX

CAN OFFSET TUNING BE APPLIED TO EDF OR FIXED-PRIORITY SCHEDULING?

➔ *yes in principle, but no equivalence guarantee*

FIFO schedule + ***offset for τ_3*** :



RM schedule + ***offset for τ_3*** :