THE CASE FOR AN OPINIONATED, THEORY-ORIENTED REAL-TIME OPERATING SYSTEM

NGOSCPS'19

April 15, 2019

Björn Brandenburg

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MAX PLANCK INSTITUTE FOR SOFTWARE SYSTEMS

European Research Council

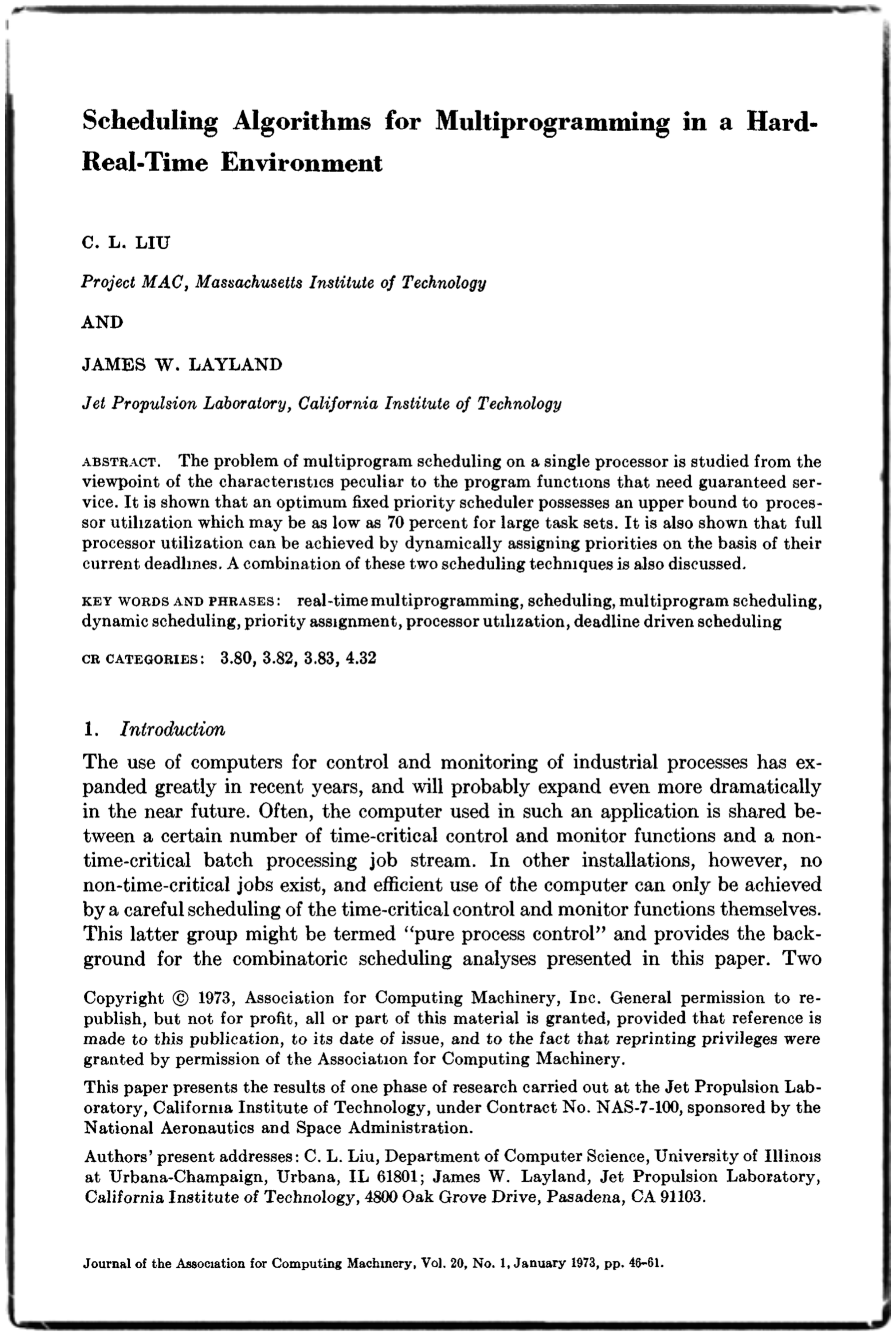
Established by the European Commission

MAX-PLANCK-GESELLSCHAFT

REAL-TIME SYSTEMS

A SUCCESS STORY

FIVE DECADES OF REAL-TIME SYSTEMS RESEARCH



Scheduling Algorithms for Multiprogramming in a Hard-Real-Time Environment

C. L. LIU

Project MAC, Massachusetts Institute of Technology

AND

JAMES W. LAYLAND

Jet Propulsion Laboratory, California Institute of Technology

ABSTRACT. The problem of multiprogram scheduling on a single processor is studied from the viewpoint of the characteristics peculiar to the program functions that need guaranteed service. It is shown that an optimum fixed priority scheduler possesses an upper bound to processor utilization which may be as low as 70 percent for large task sets. It is also shown that full processor utilization can be achieved by dynamically assigning priorities on the basis of their current deadlines. A combination of these two scheduling techniques is also discussed.

KEY WORDS AND PHRASES: real-time multiprogramming, scheduling, multiprogram scheduling, dynamic scheduling, priority assignment, processor utilization, deadline driven scheduling

CR CATEGORIES: 3.80, 3.82, 3.83, 4.32

1. *Introduction*

The use of computers for control and monitoring of industrial processes has expanded greatly in recent years, and will probably expand even more dramatically in the near future. Often, the computer used in such an application is shared between a certain number of time-critical control and monitor functions and a non-time-critical batch processing job stream. In other installations, however, no non-time-critical jobs exist, and efficient use of the computer can only be achieved by a careful scheduling of the time-critical control and monitor functions themselves. This latter group might be termed "pure process control" and provides the background for the combinatoric scheduling analyses presented in this paper. Two

This paper presents the results of one phase of research carried out at the Jet Propulsion Laboratory, California Institute of Technology, under Contract No. NAS-7-100, sponsored by the National Aeronautics and Space Administration.

Authors' present addresses: C. L. Liu, Department of Computer Science, University of Illinois at Urbana-Champaign, Urbana, IL 61801; James W. Layland, Jet Propulsion Laboratory, California Institute of Technology, 4800 Oak Grove Drive, Pasadena, CA 91103.

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(Liu & Layland, 1973)

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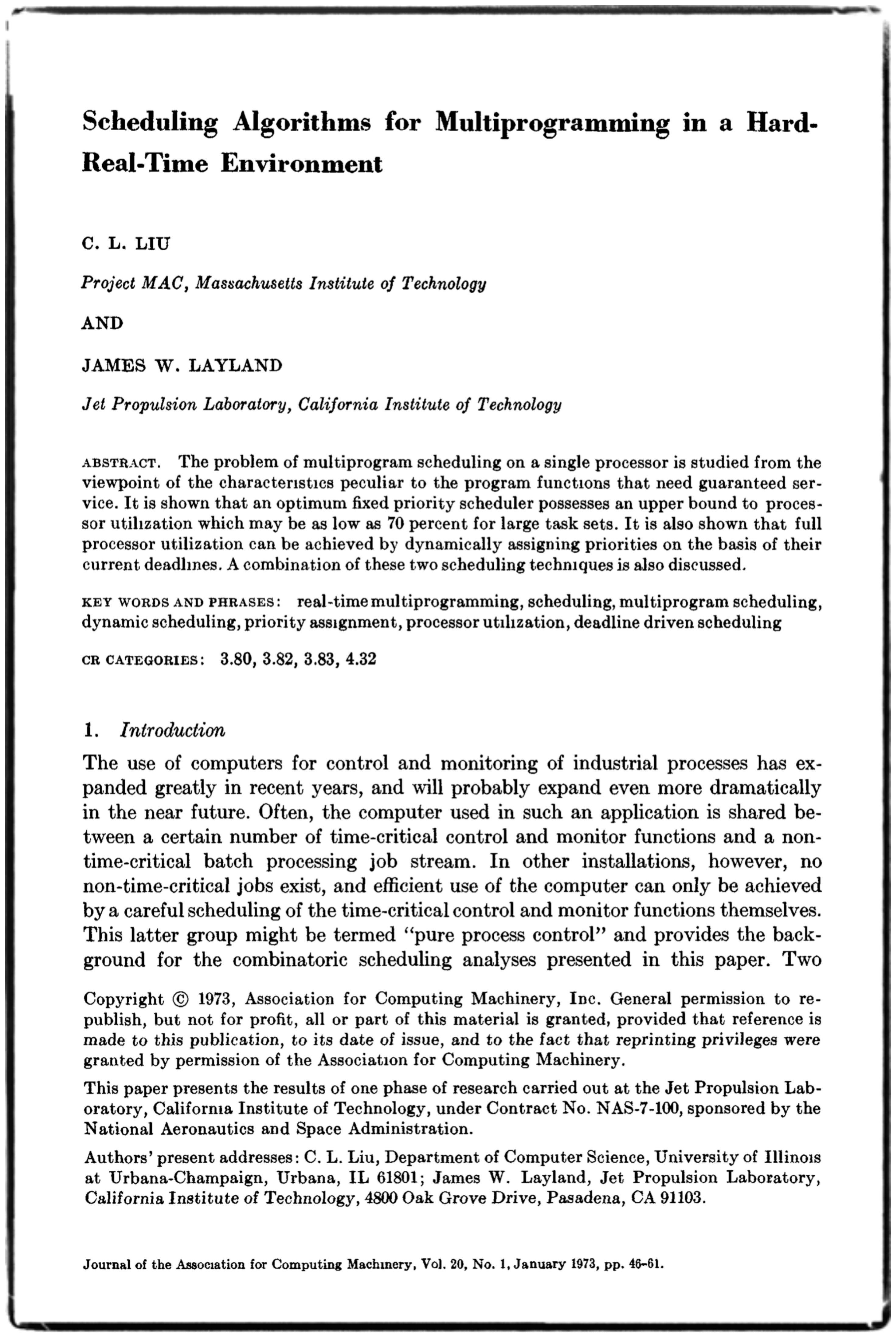

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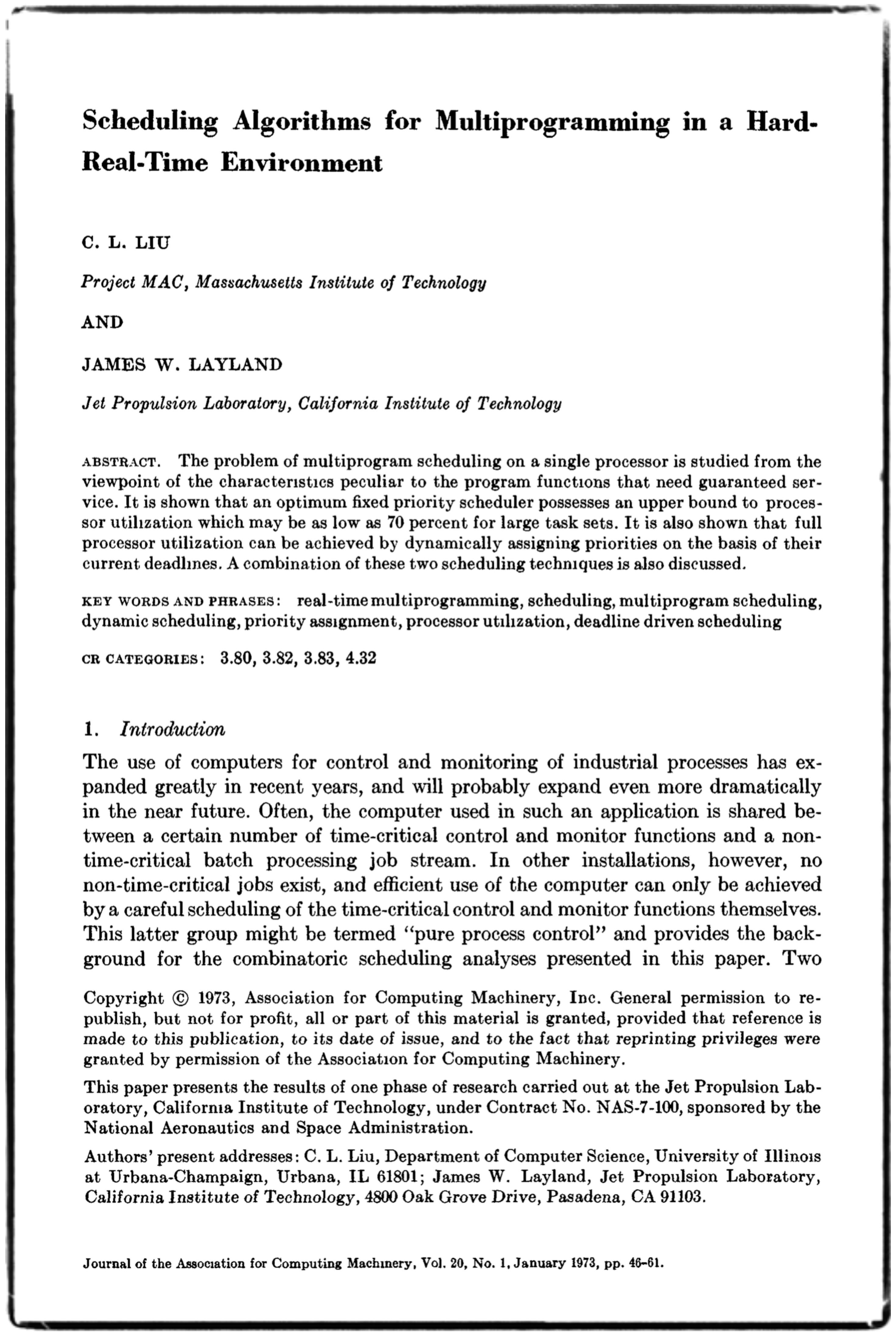

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➔ *(where) does this get used in practice???*

MAJOR USERS OF REAL-TIME SYSTEMS TECHNOLOGY

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BOEING
AIRBUS
BOSCH
THALES
DENSO
Crafting the Core
Honeywell
ABB
Rockwell Collins

To name just a few examples…

MAJOR USERS OF REAL-TIME SYSTEMS TECHNOLOGY

Large international companies with
large R&D budgets and **dedicated real-time specialists**

➔ *Tremendous amount of in-house real-time expertise!*

MAJOR USERS OF REAL-TIME SYSTEMS TECHNOLOGY

Define "use"...

...formal, sound timing analysis?

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BUT WHAT ABOUT USERS IN THE "LONG TAIL"?

much expertise → little expertise

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BOEING AIRBUS

BOSCH THALES

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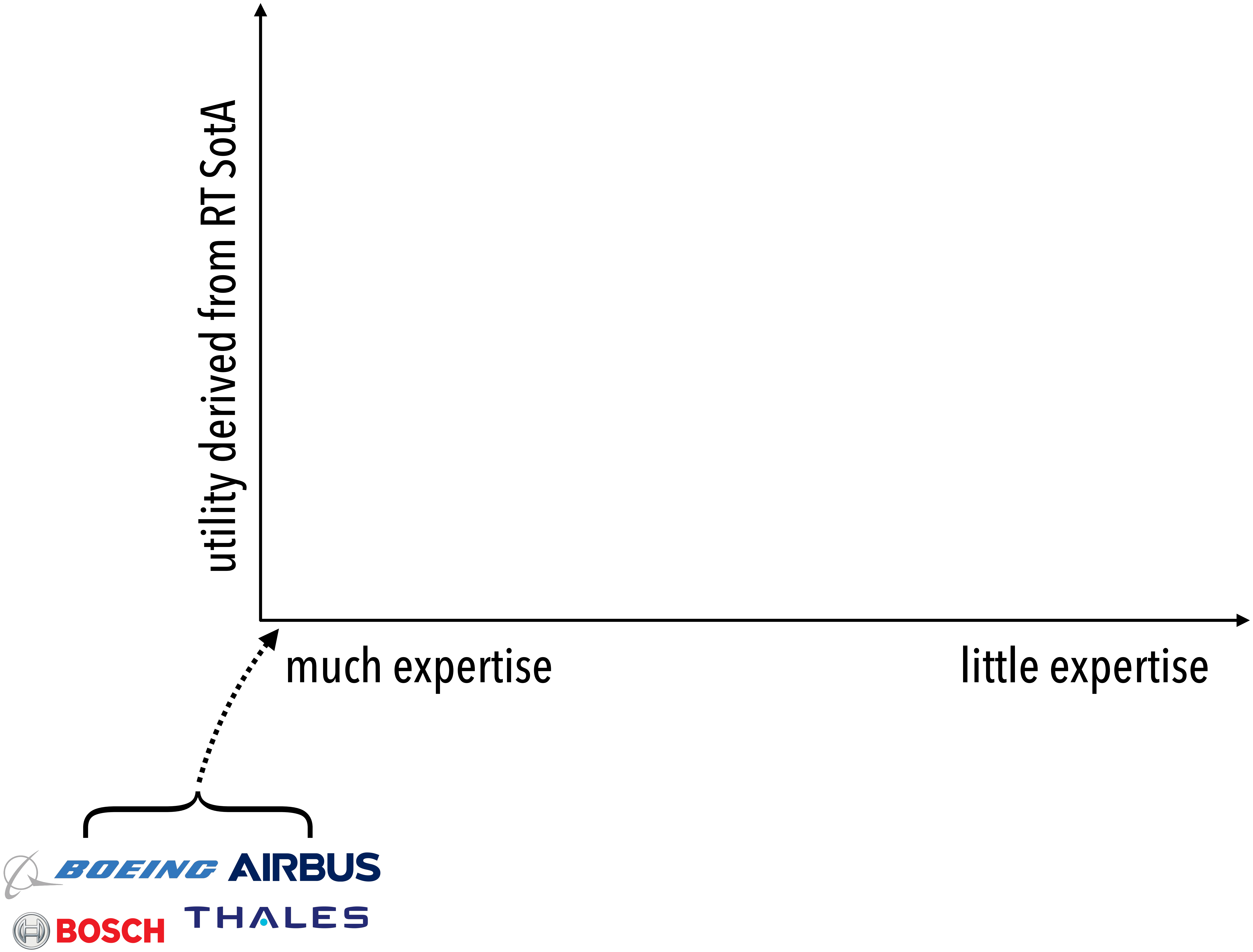

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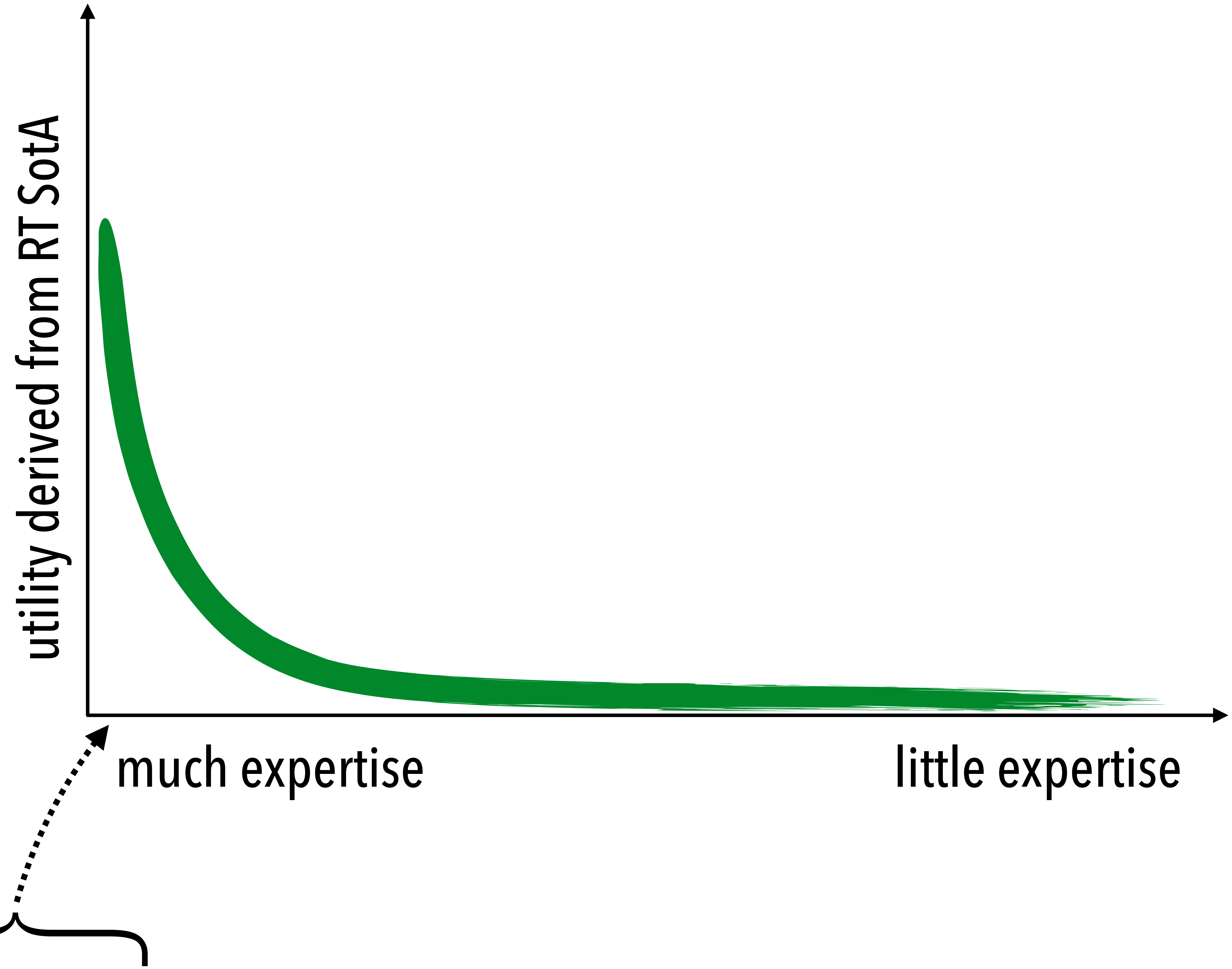

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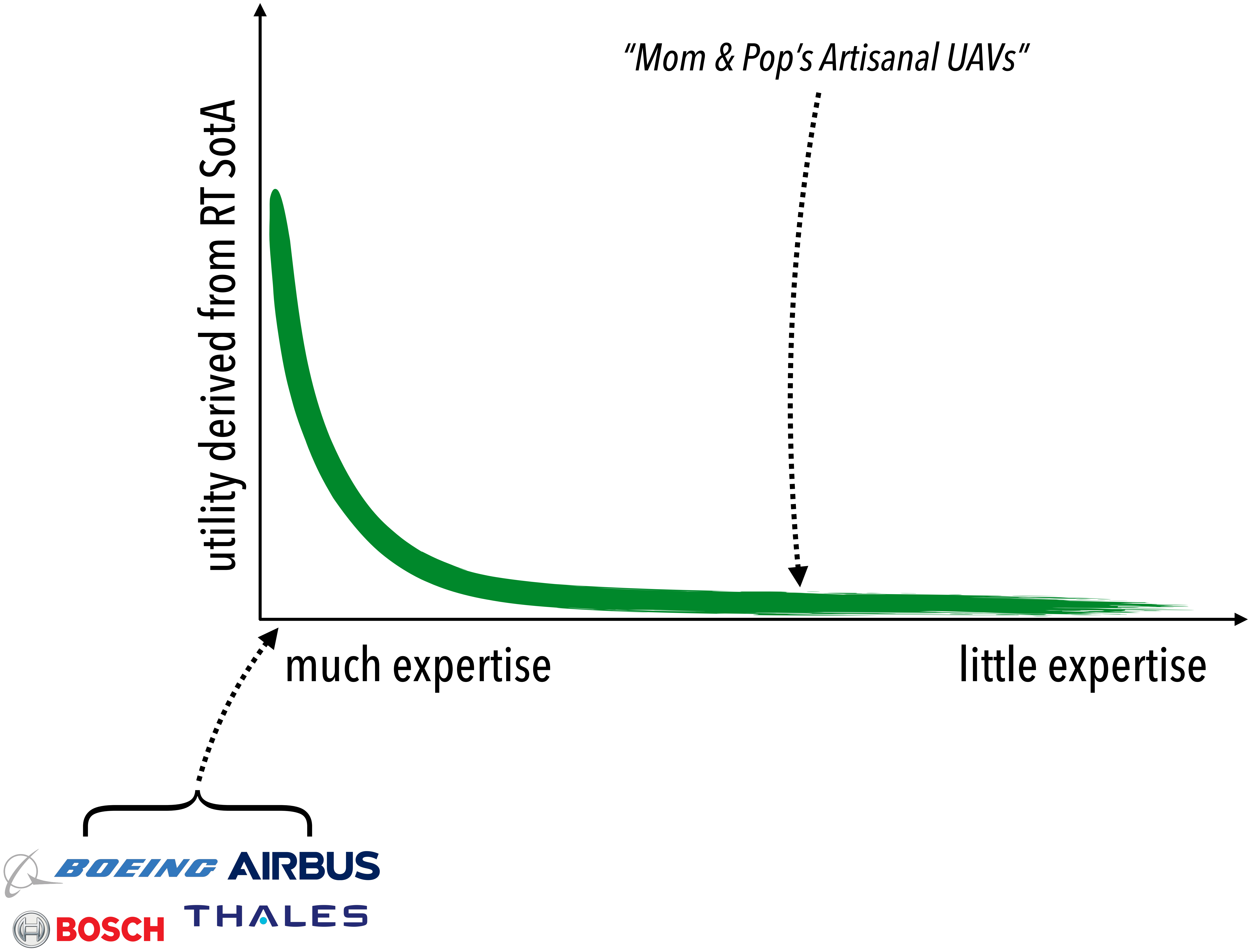

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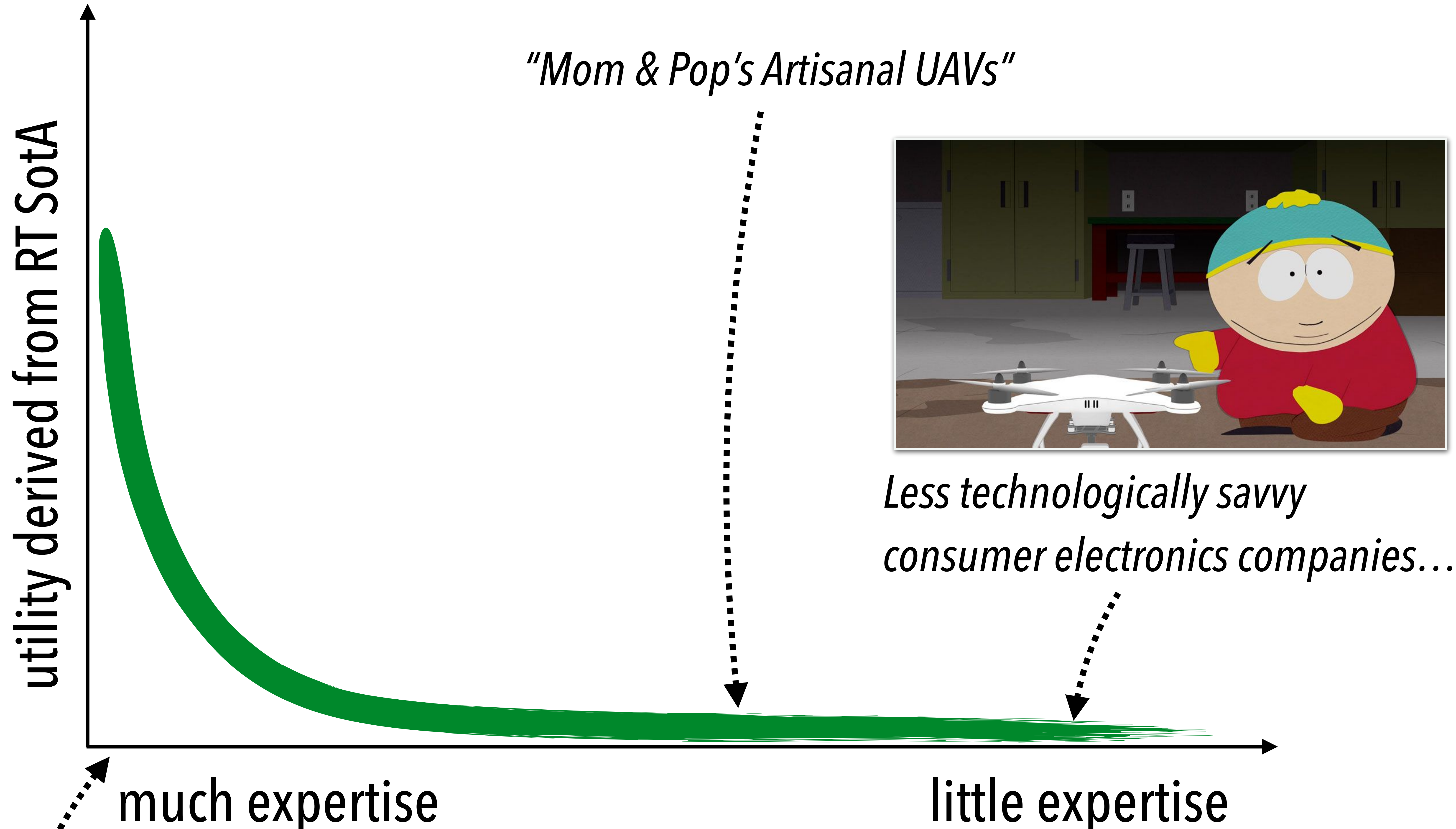
"Mom & Pop's Artisanal UAVs"



Less technologically savvy consumer electronics companies…

BOEING AIRBUS
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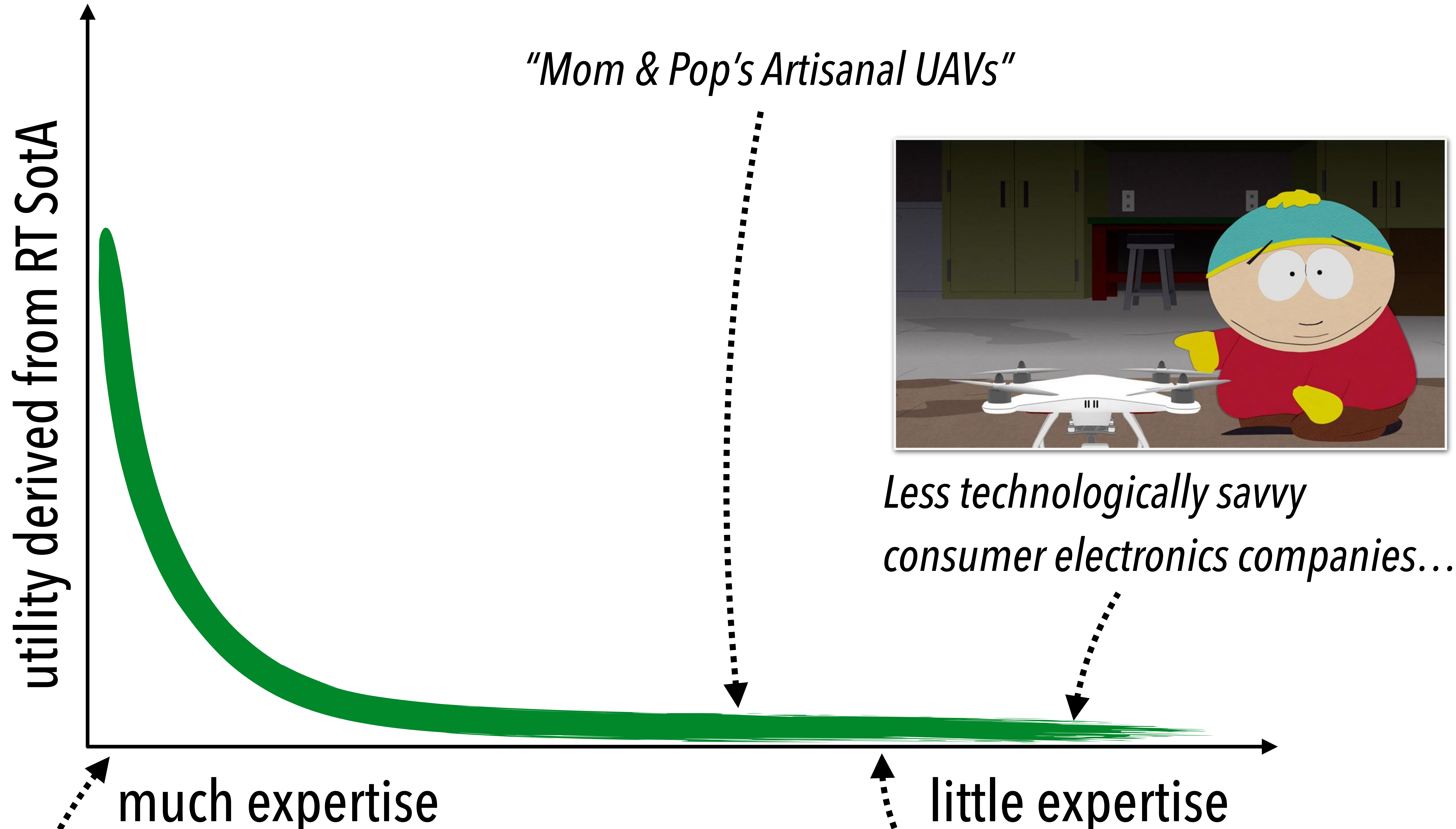

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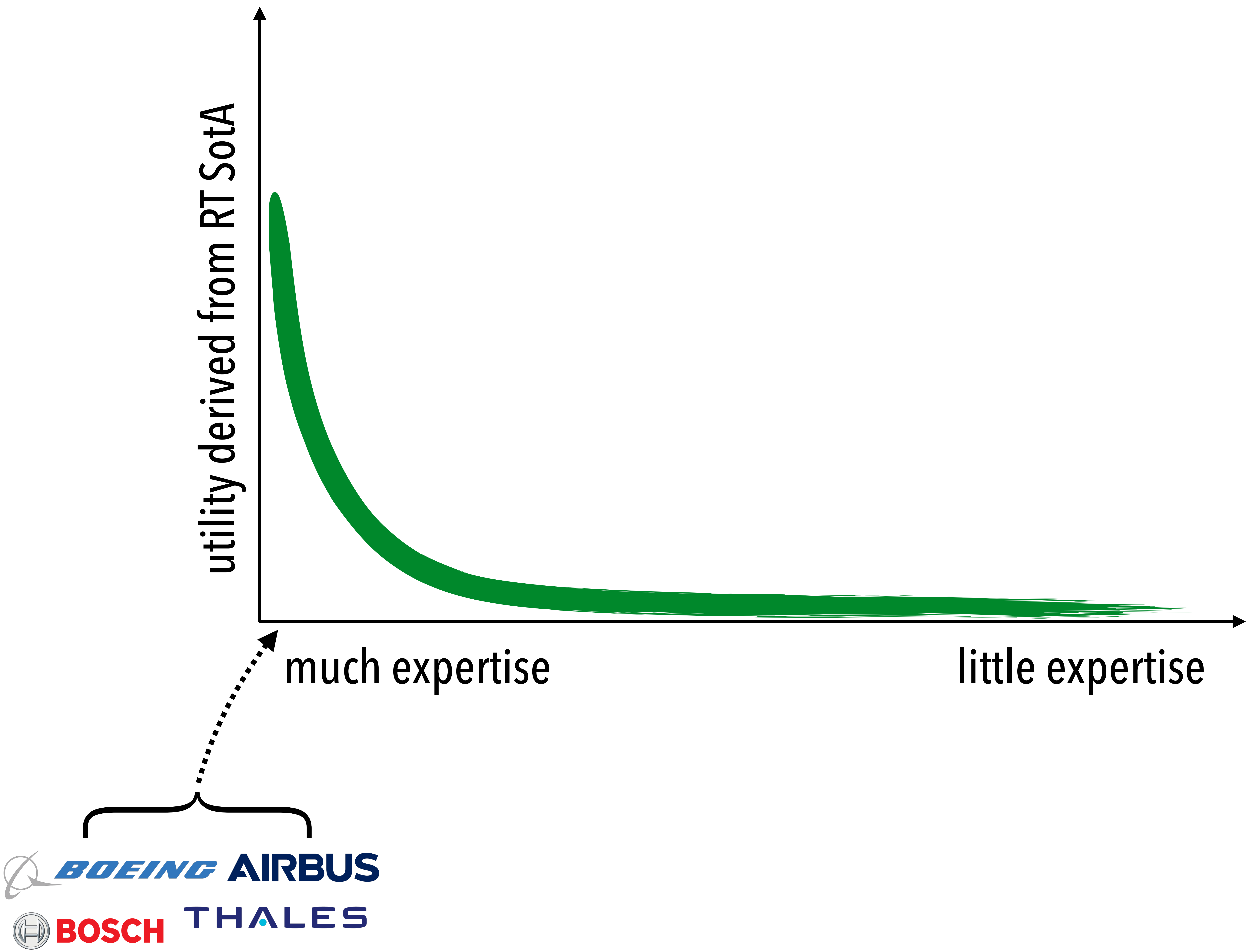
BOEING AIRBUS BOSCH THALES

Download Linux & PREEMPT-RT & ROS

➔ *many applied robotics **researchers**…*

MOTIVATING OBSERVATION



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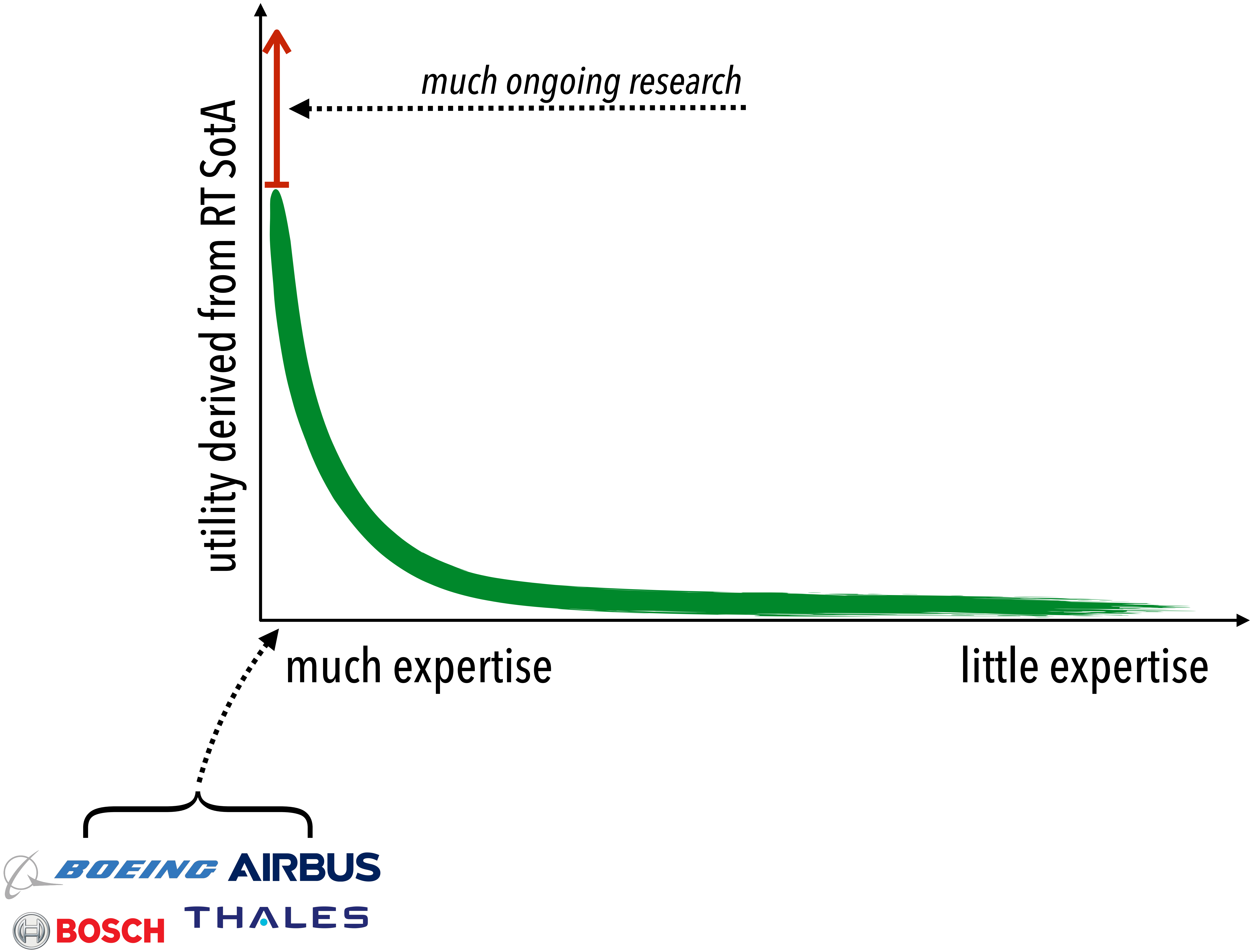

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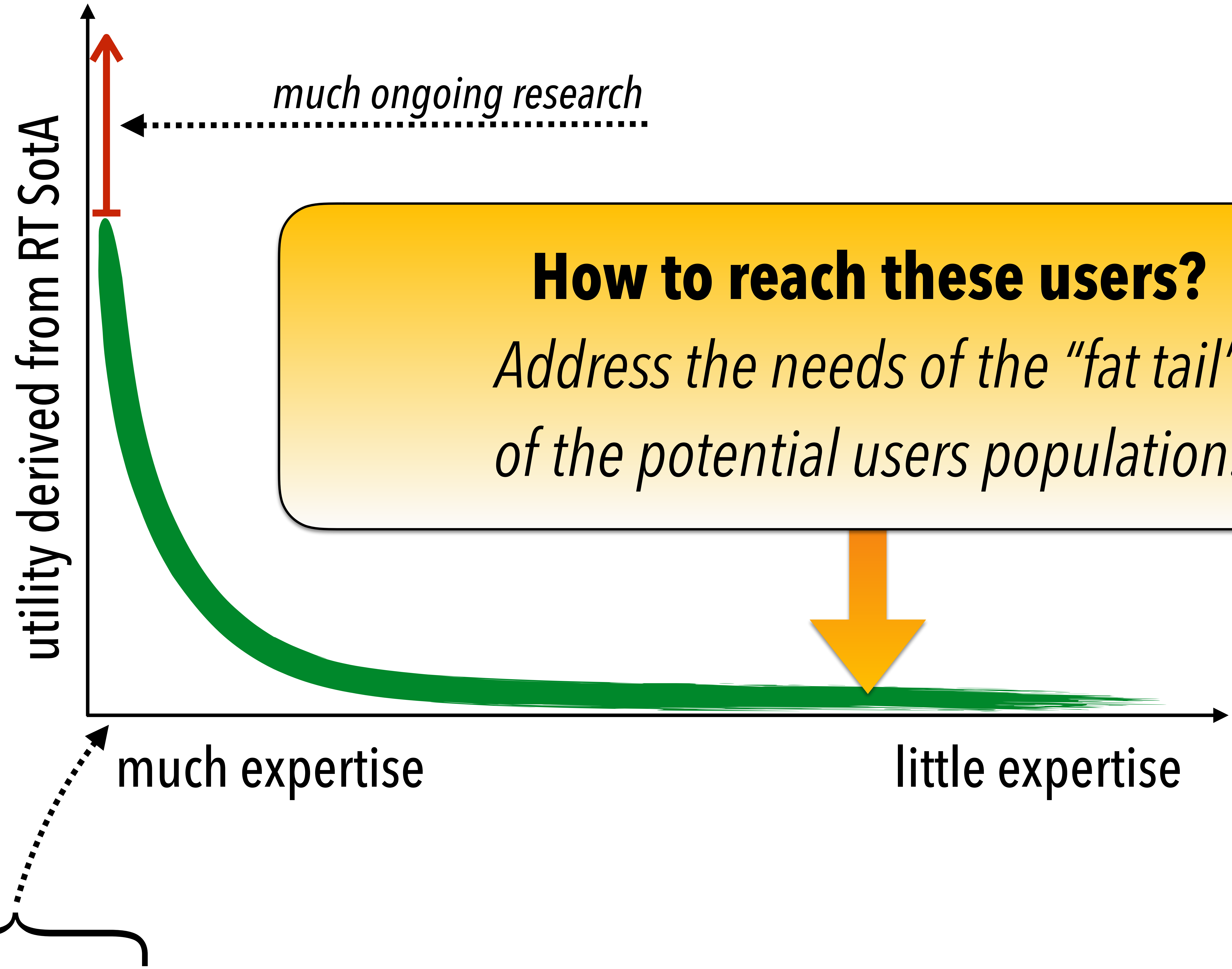

How to reach these users?

Address the needs of the "fat tail" of the potential users population.

BOEING AIRBUS
BOSCH THALES

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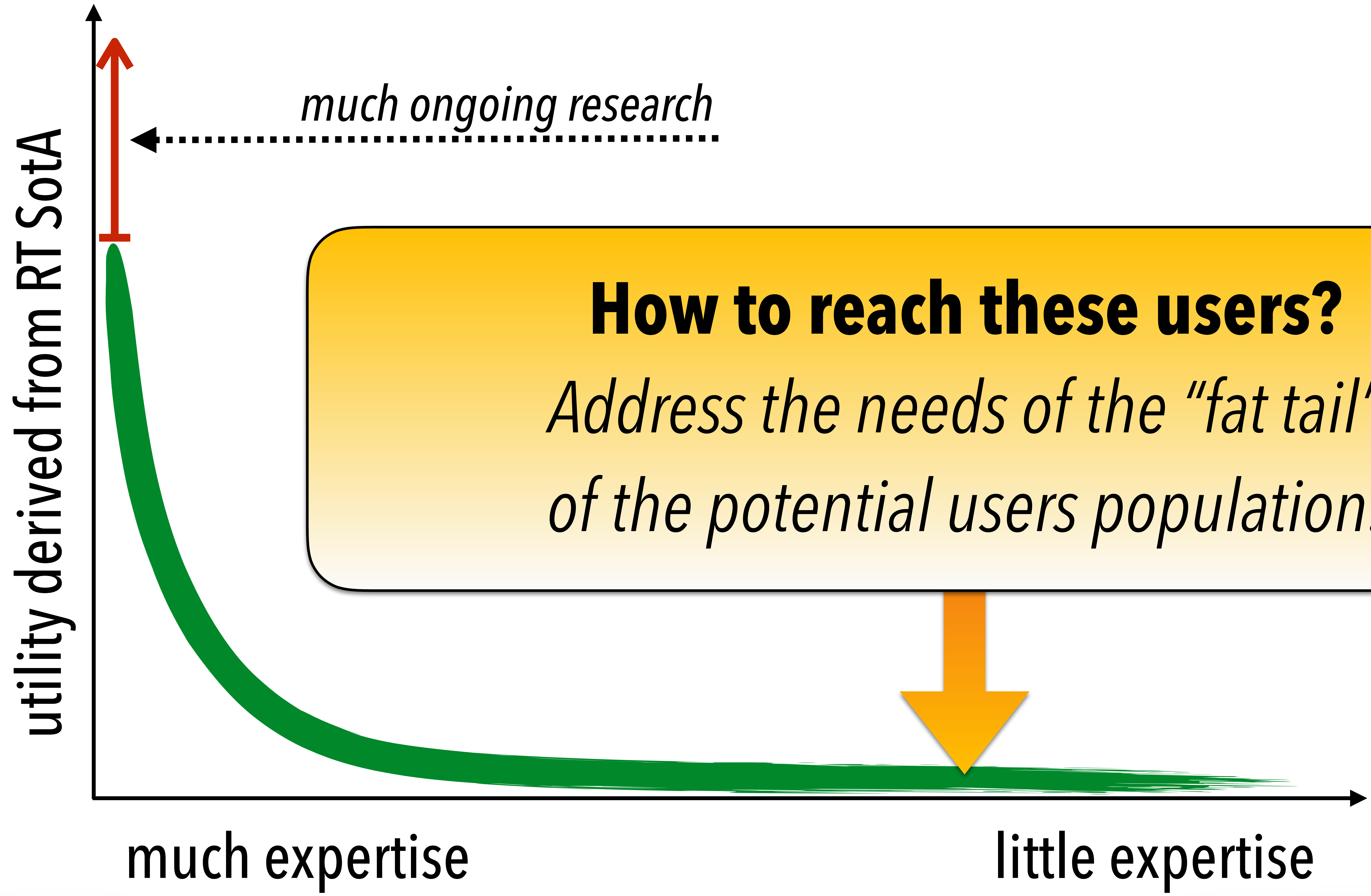

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Central Question

What prevents the widespread use of temporally sound system design?

HURDLES TO ADOPTION

EXPERTISE BARRIER

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In theory:
temporally sound, predictable system amenable to formal analysis

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Don't need to be a compact flash expert to store a file…!
Don't need to be a concurrency control expert to query a database…!

COMPLEX TOOLING

Who wants to add "yet another tool" as a build dependency?

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Static Timing Analysis Tooling Today

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not exactly user-friendly

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This may work for customers that **can't avoid** it…

…but it won't **entice users** in the "tail".

WHAT IF: `/proc/$PID/max-response-time—estimate`

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Suppose:

- ➔ wake-ups of `SCHED_FIFO` tasks **automatically** tracked
  - *over finite window (e.g., one second)*
- ➔ re-compute response-time bound whenever observations change
  - *based on **observed** peak arrivals and **observed** CPU consumption*
- ➔ does not require periodicity: can be represented as an *arrival curve*

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- ➔ online monitoring (top)
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➔ *much higher confidence from existing testing*

ADAPTIVE BELOW-WORST-CASE PROVISIONING

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Standard Assumptions in the RT Literature

➔ static workload

➔ **worst-case execution times** (WCETs) known *a priori*

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➔ **cost-efficient** commodity multicore platforms ➔ ***no WCETs!***

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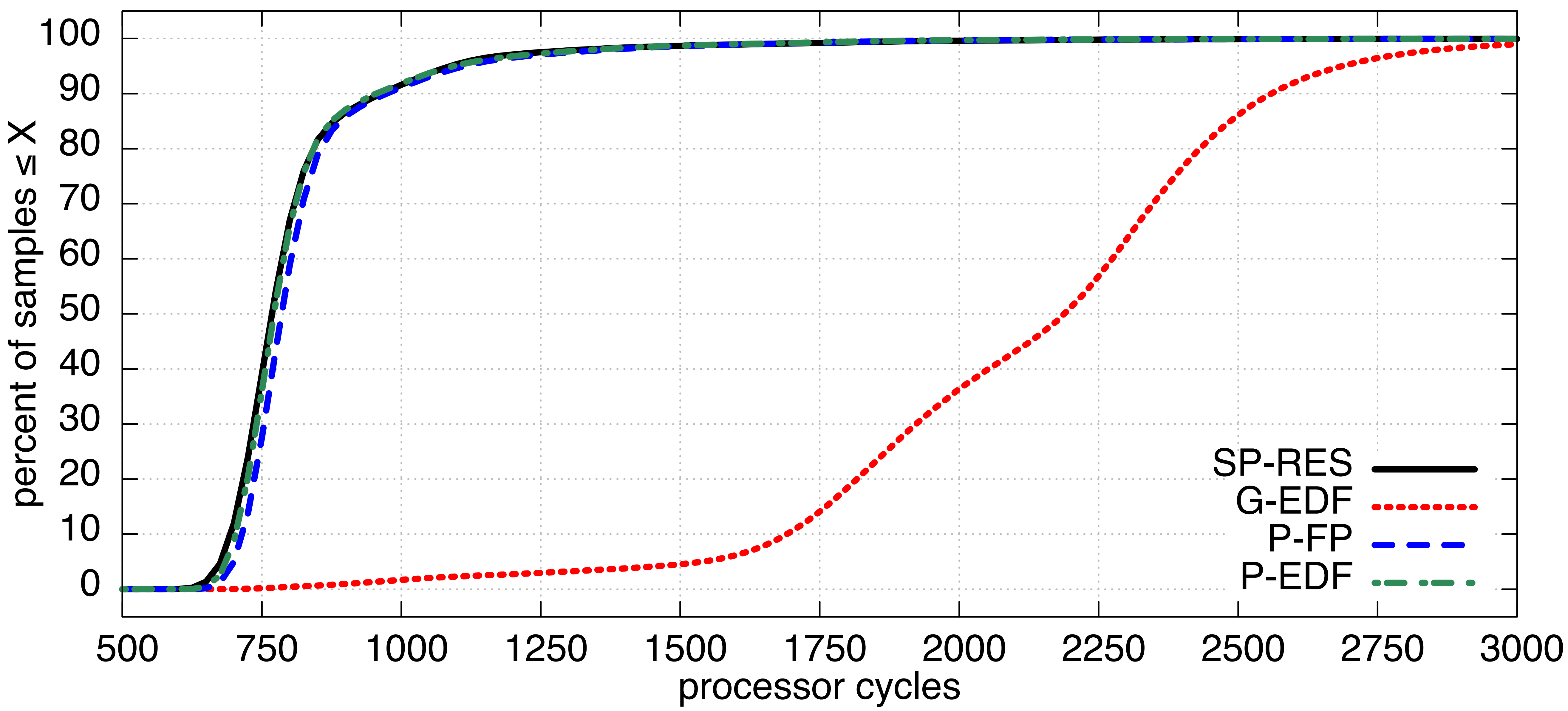
The essence of real-world engineering is graceful degradation

rather than static worst-case guarantees that are established once and then hold "forever".

EXAMPLE: CONTEXT-SWITCH OVERHEAD



LITMUS^{RT}

Linux Testbed for Multiprocessor Scheduling in Real-Time Systems

Xeon E5-2699 v4 @ 2.2 GHz

[RTSS'16]

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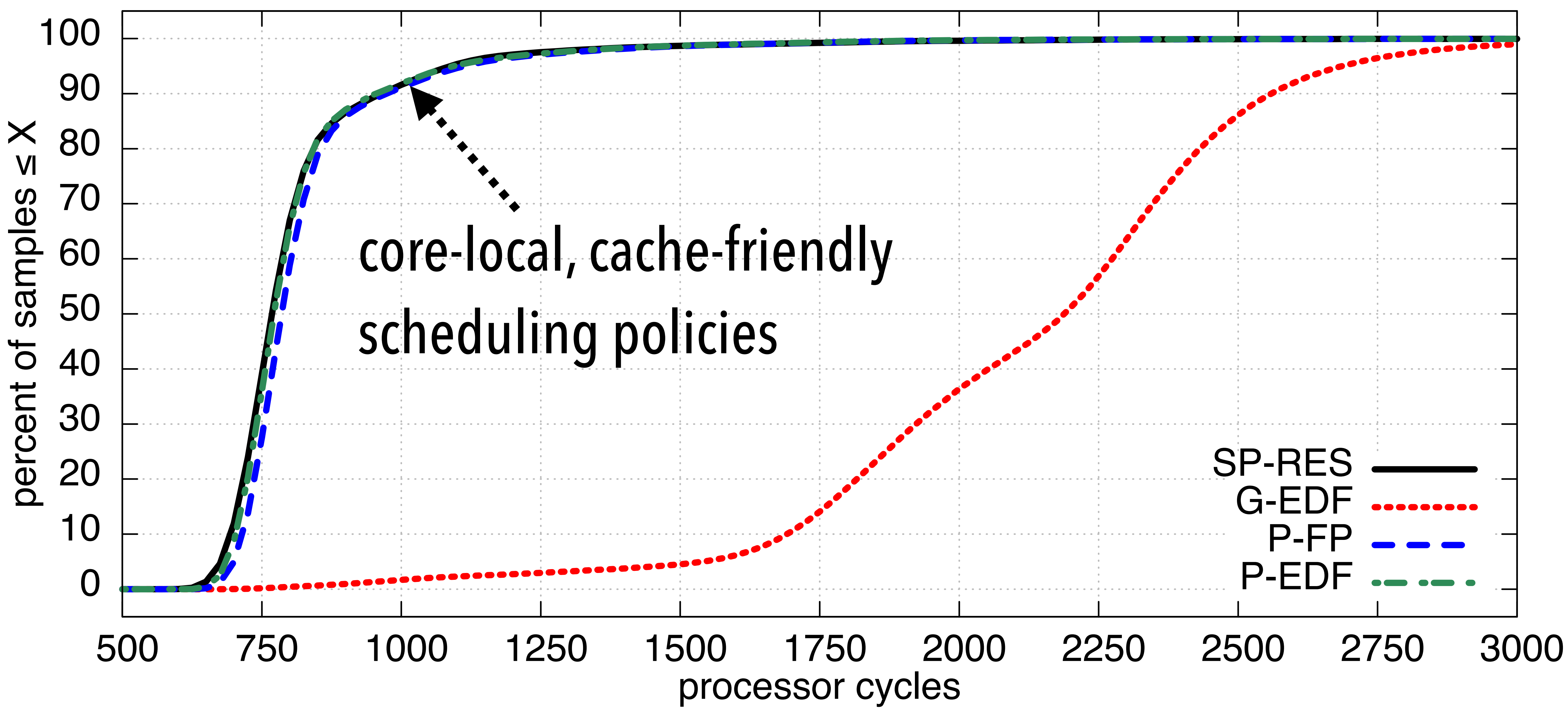

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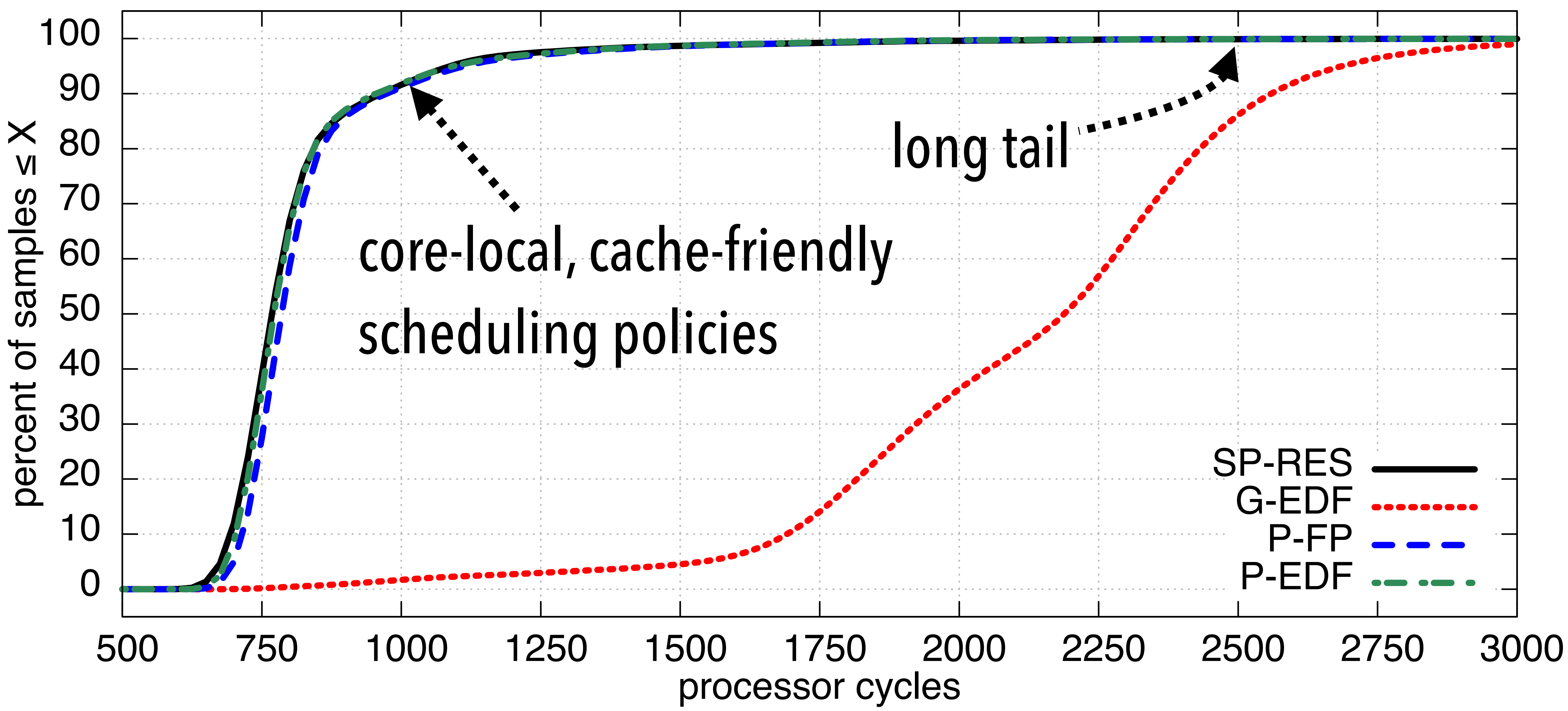

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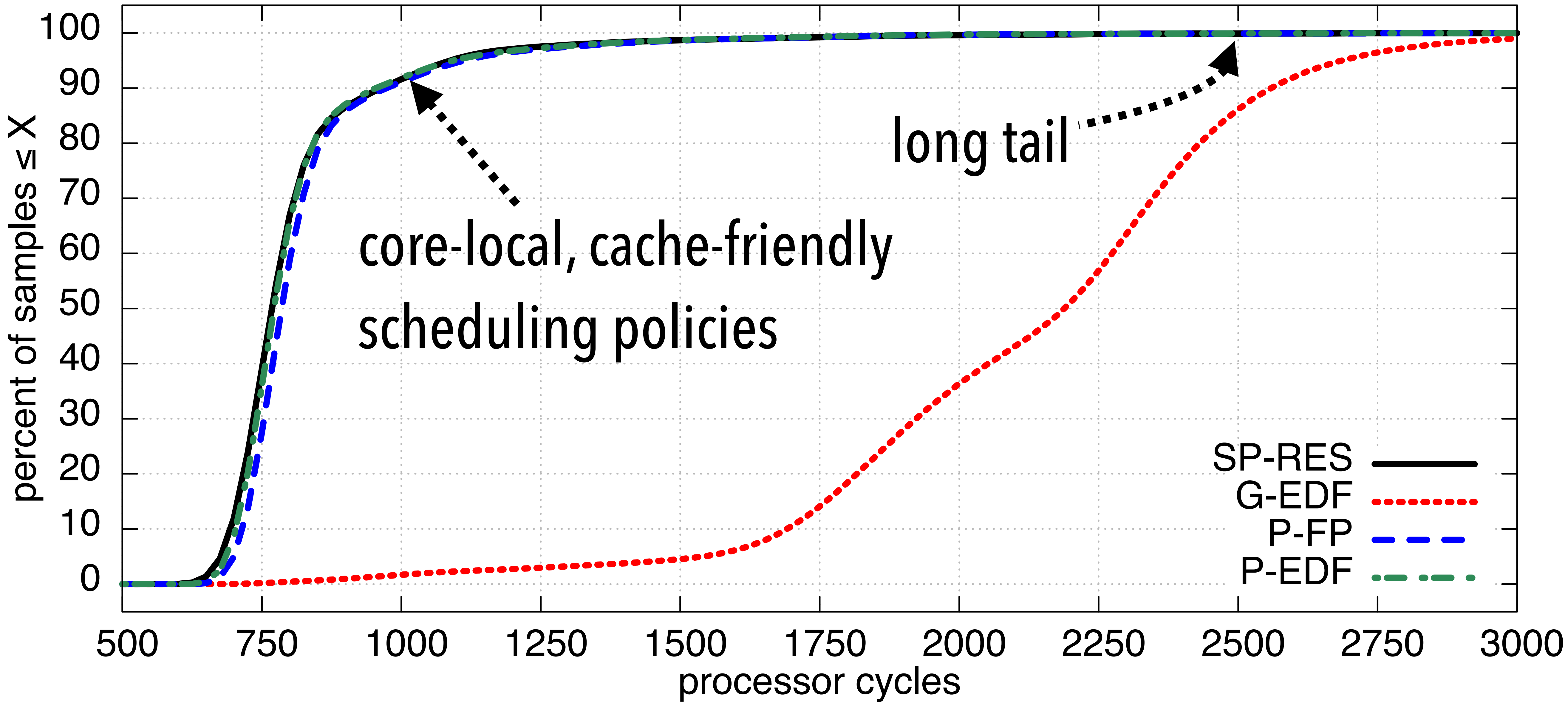

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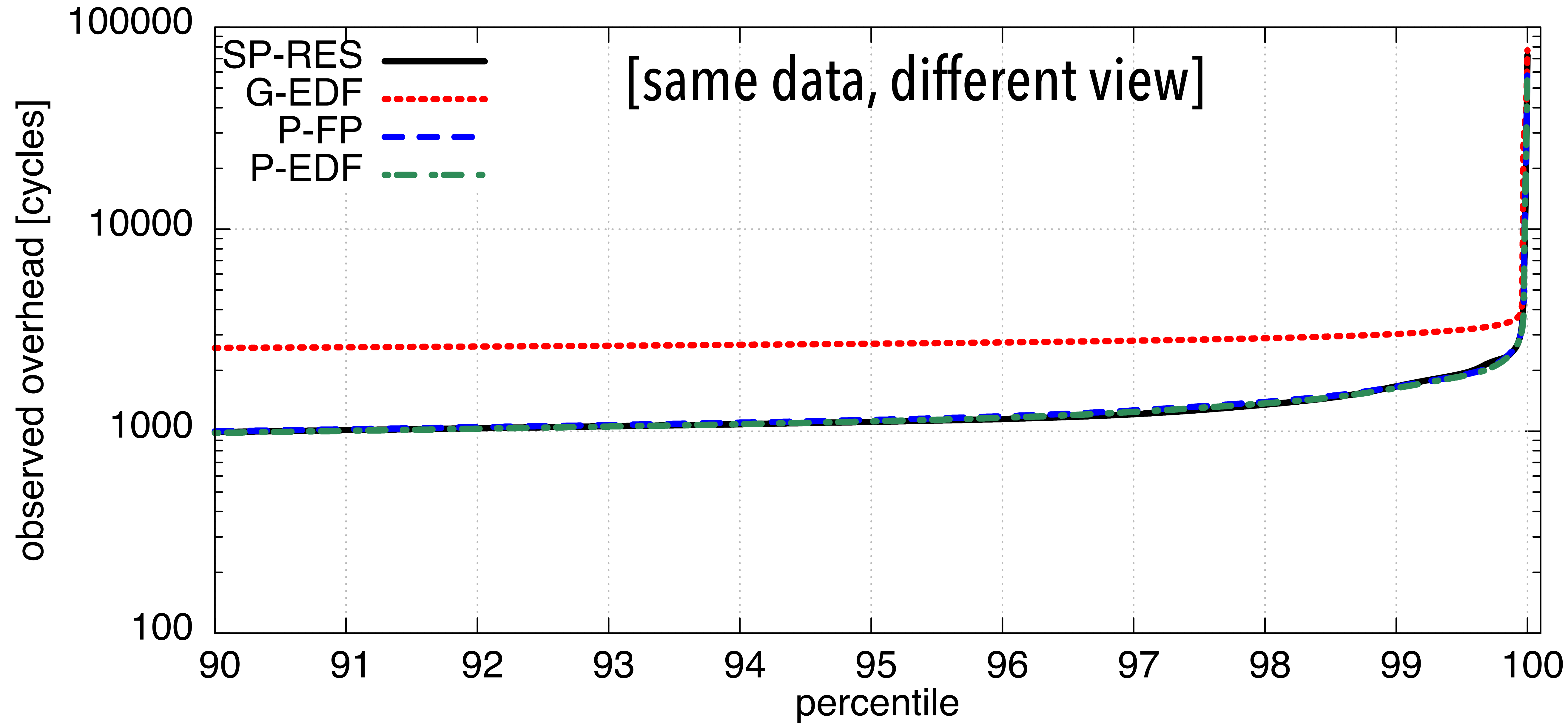

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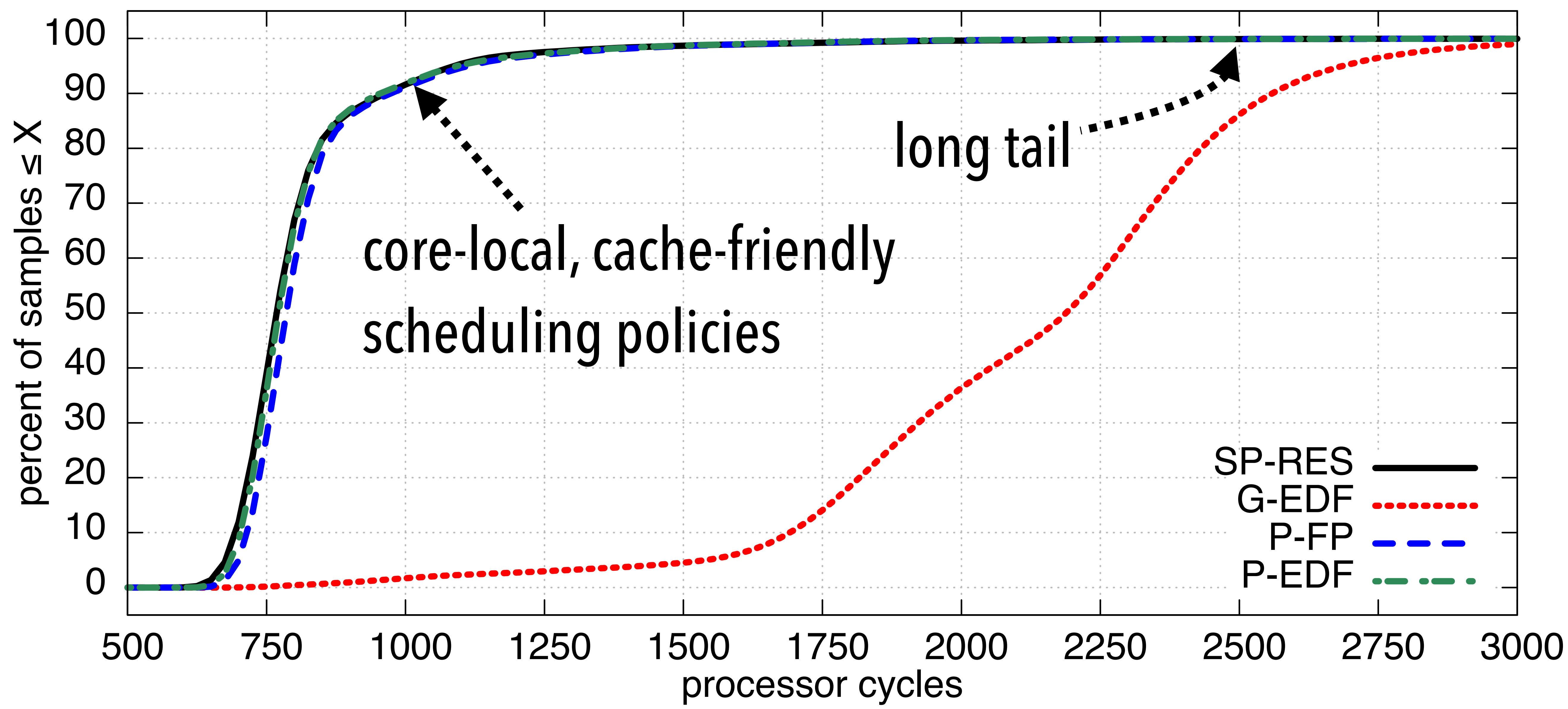

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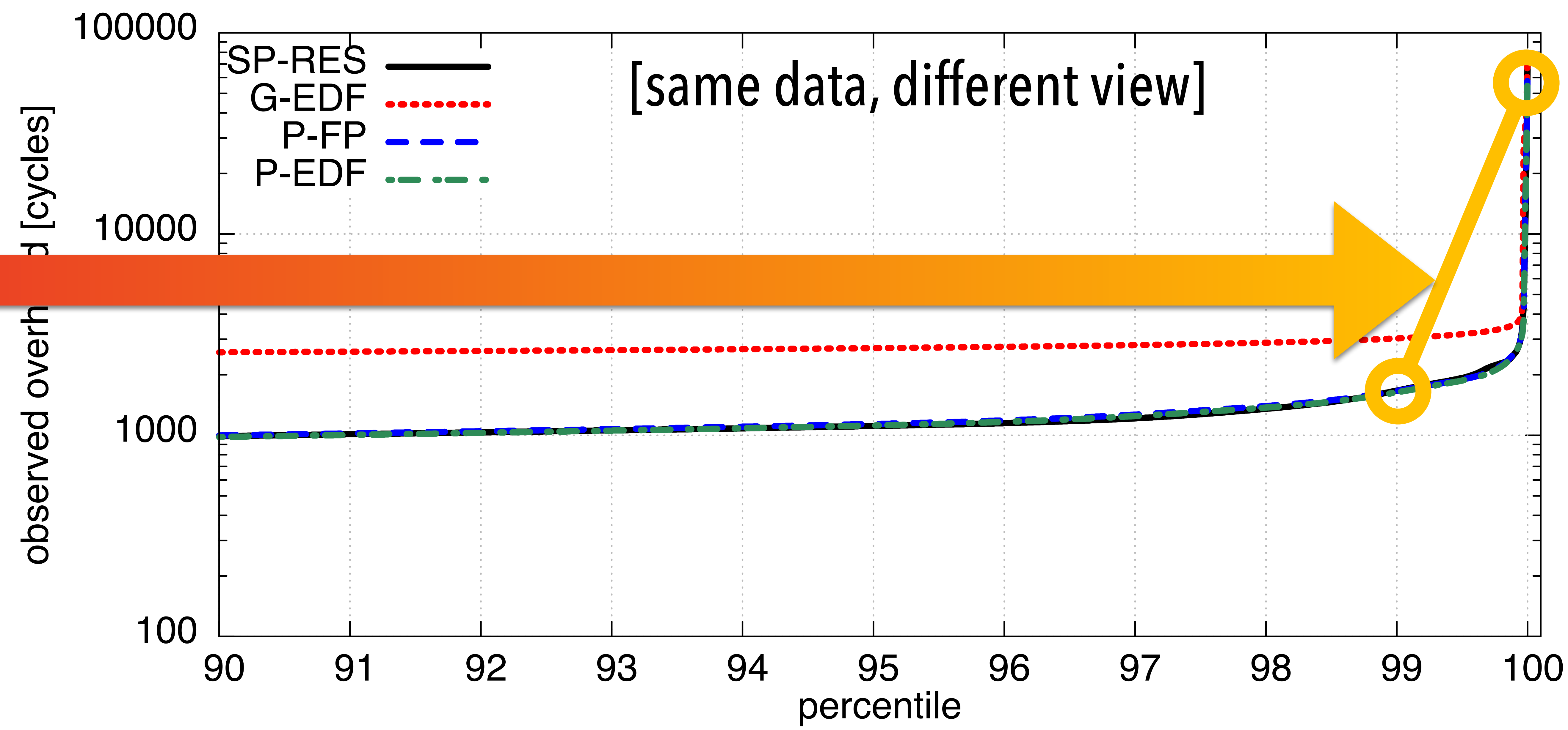
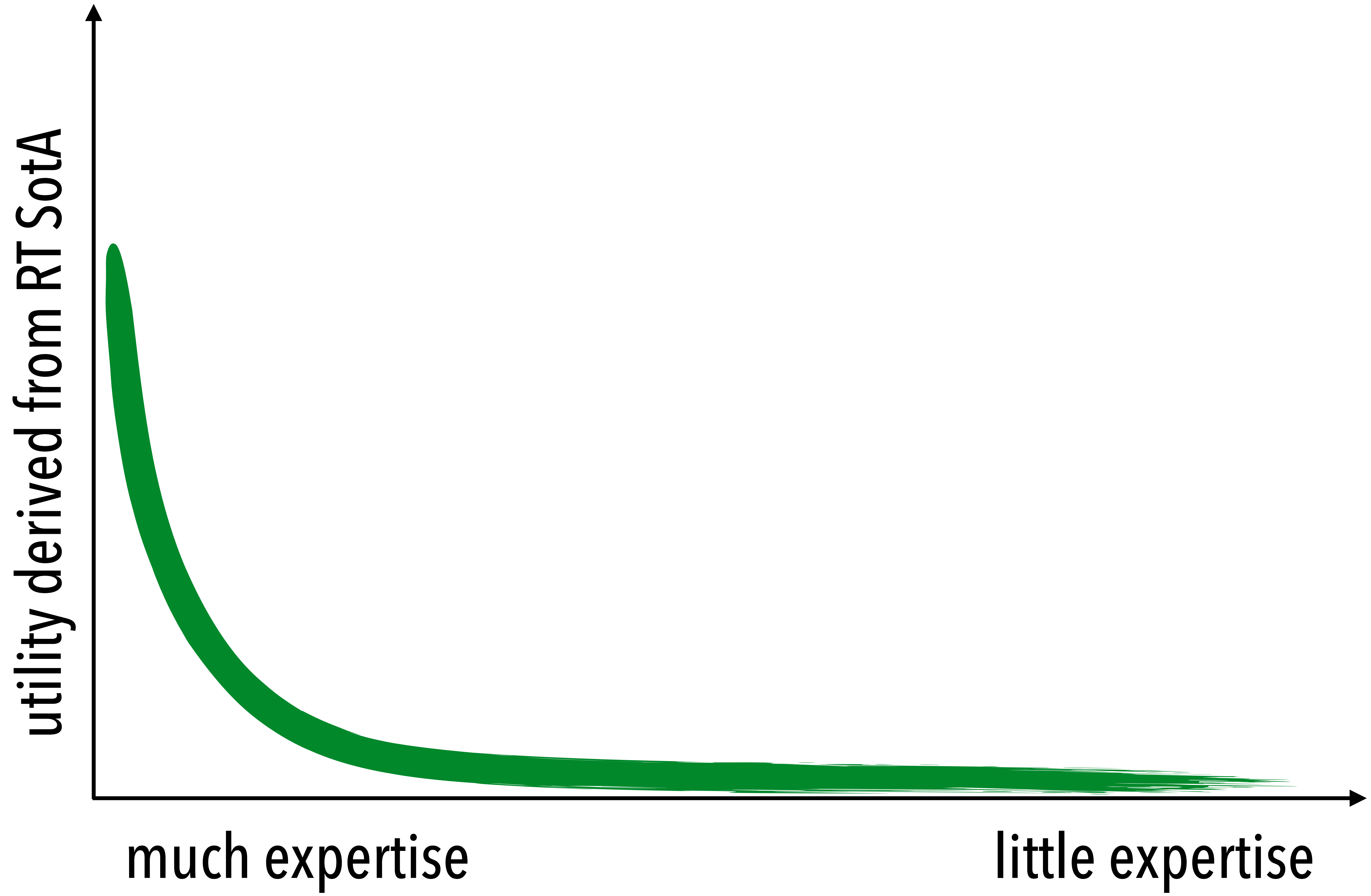
[RTSS'16]

>10× delta
between 99th percentile
and ***observed*** *maximum!*



THE PROBLEM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much expertise
little expertise

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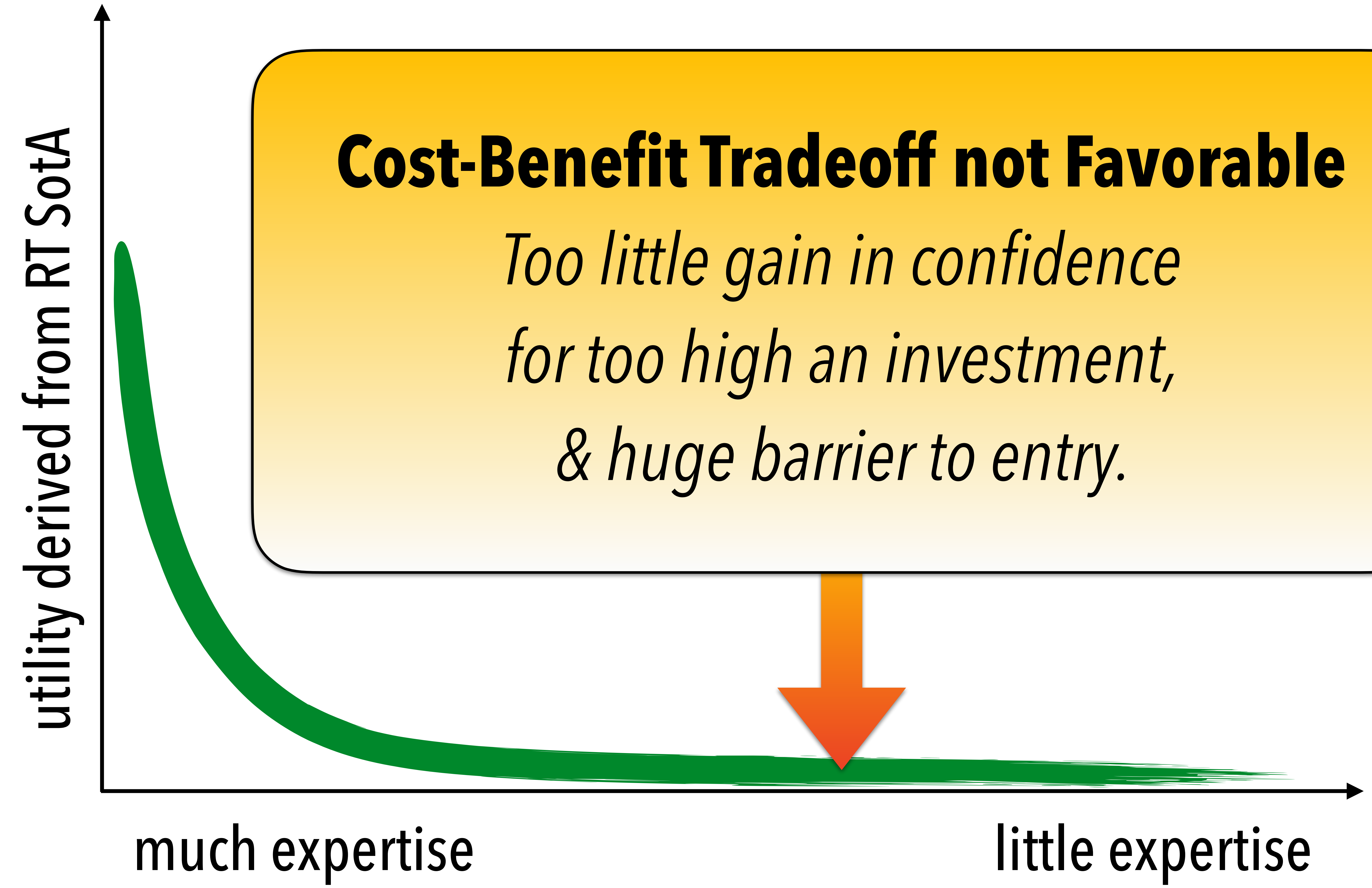
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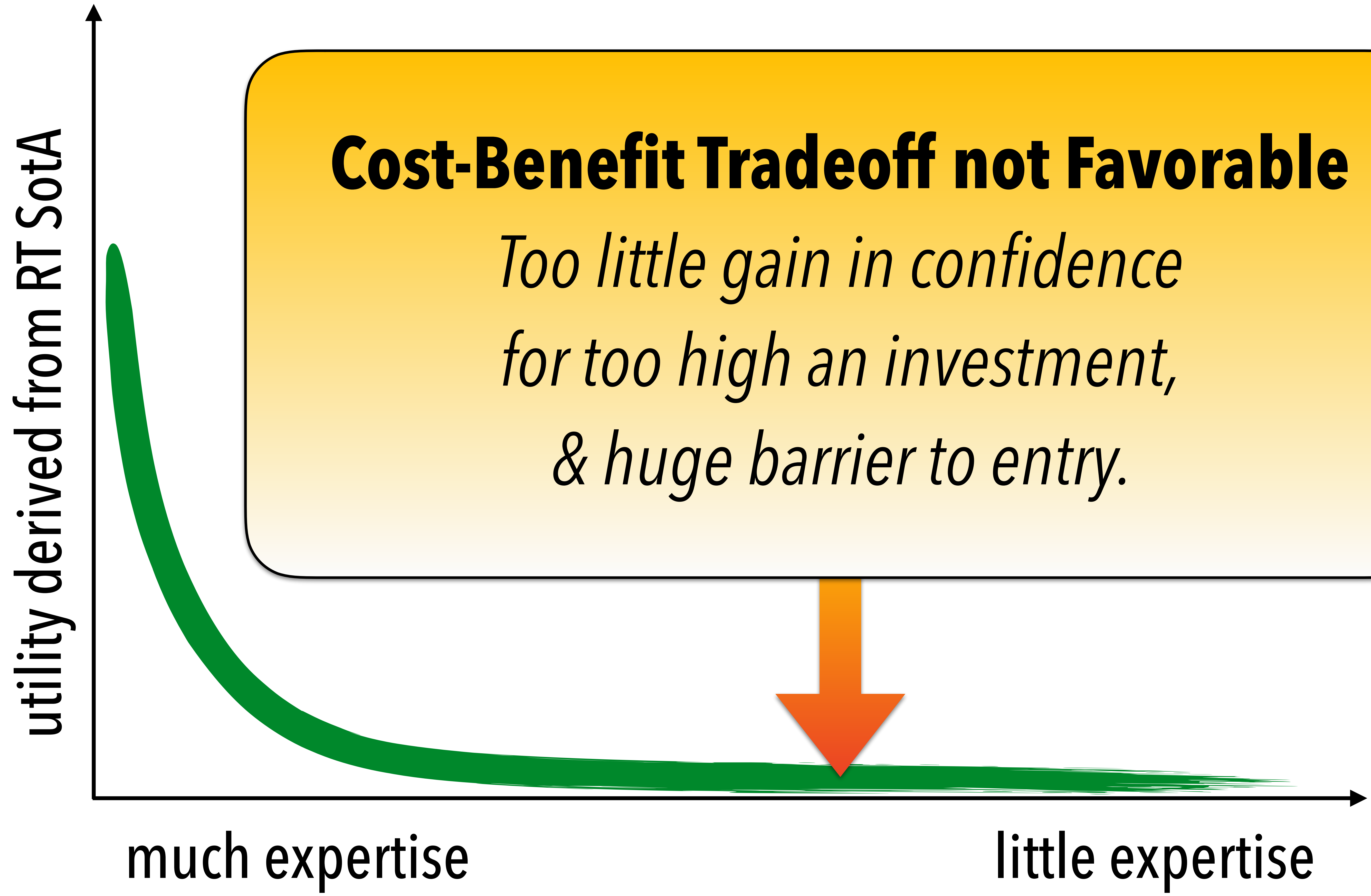

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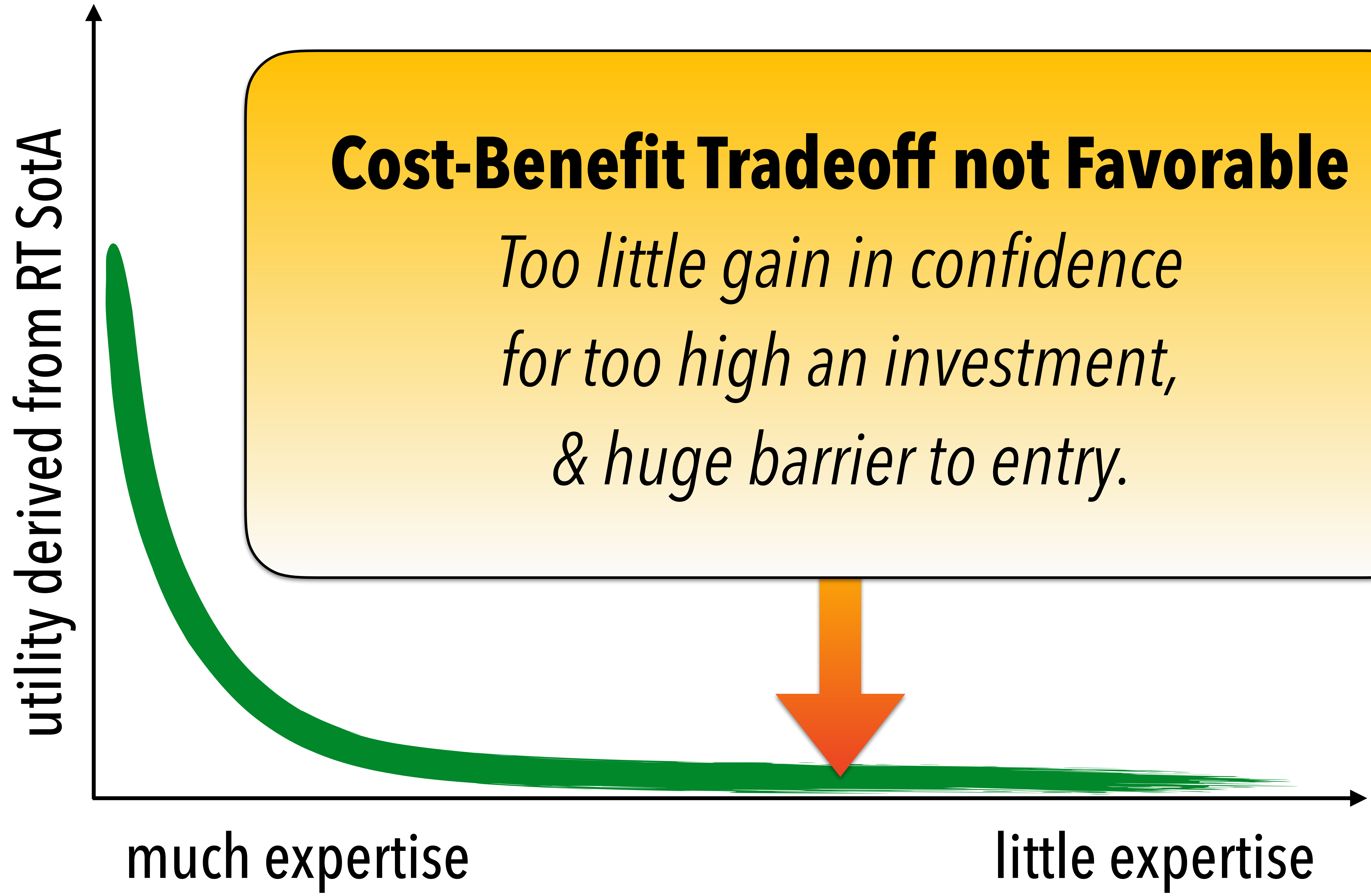

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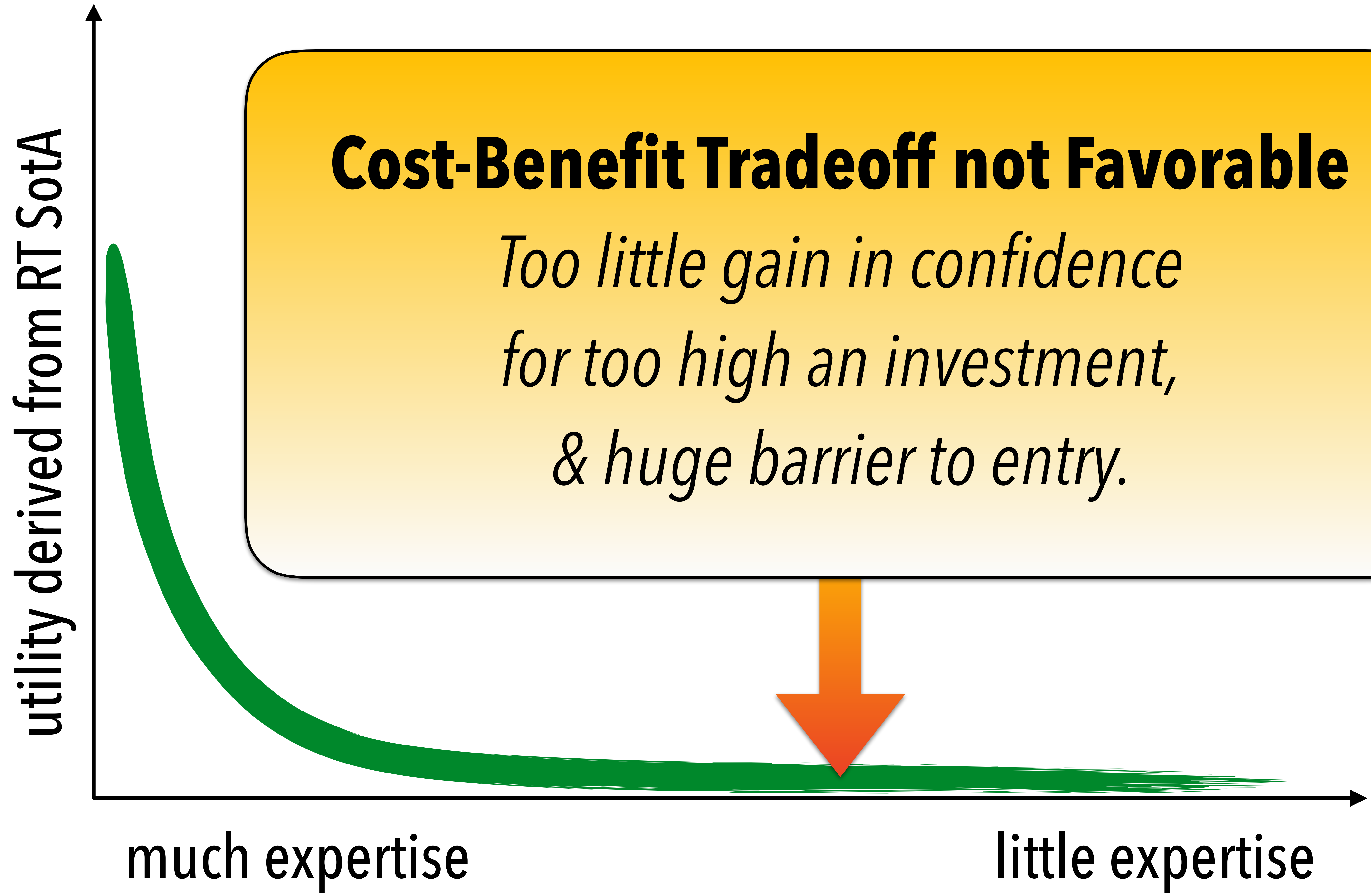

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Lack of confidence in soundness of complex analyses

Theory-
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Real-time
Operating
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A
radically different,
practical foundation
for temporally sound
cyber-physical systems

European Research Council
Established by the European Commission

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provably *free of timing errors*
(with high confidence)

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theory-first approach*: intersection of multiprocessor real-time scheduling theory and RTOS design*

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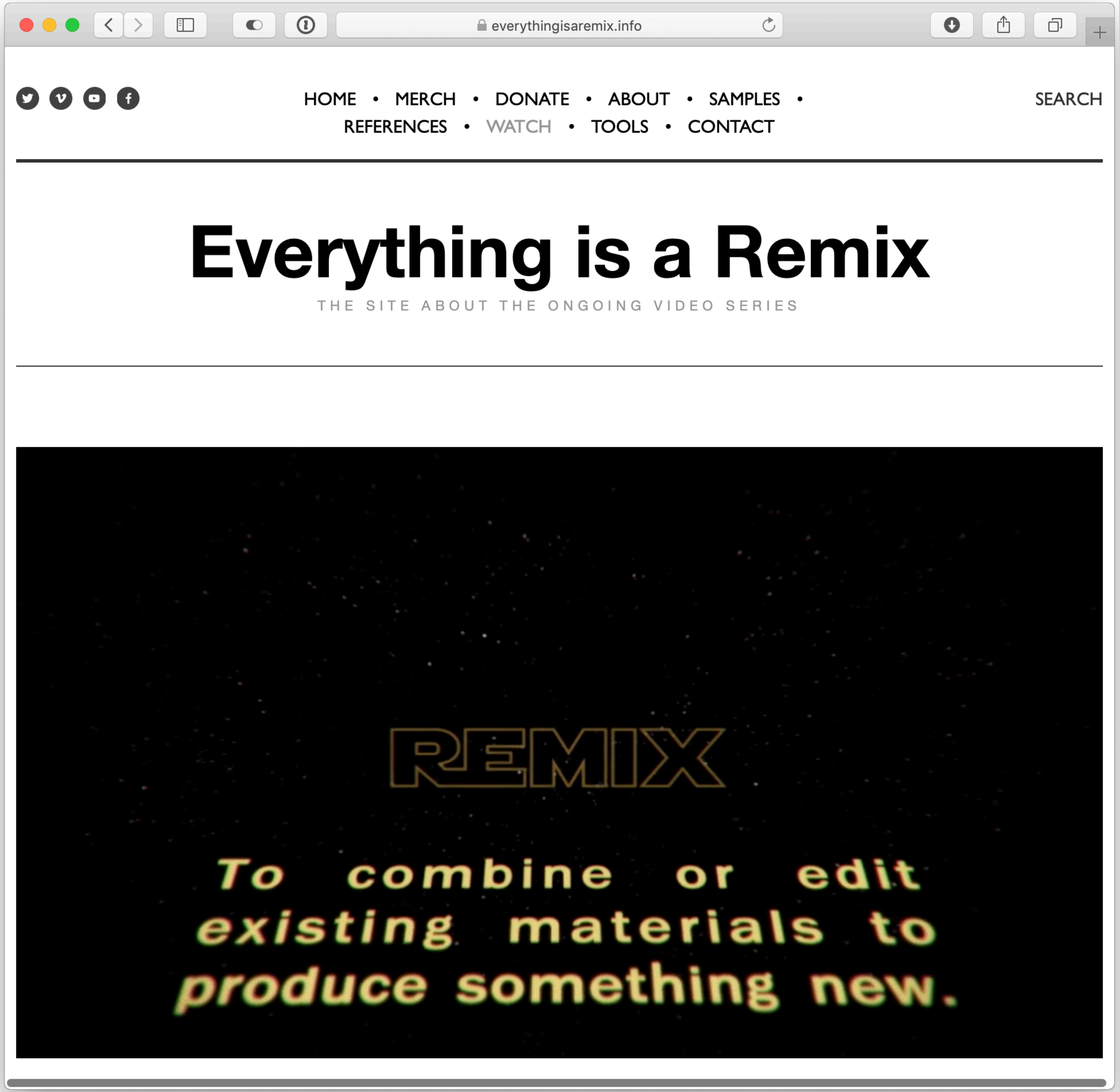
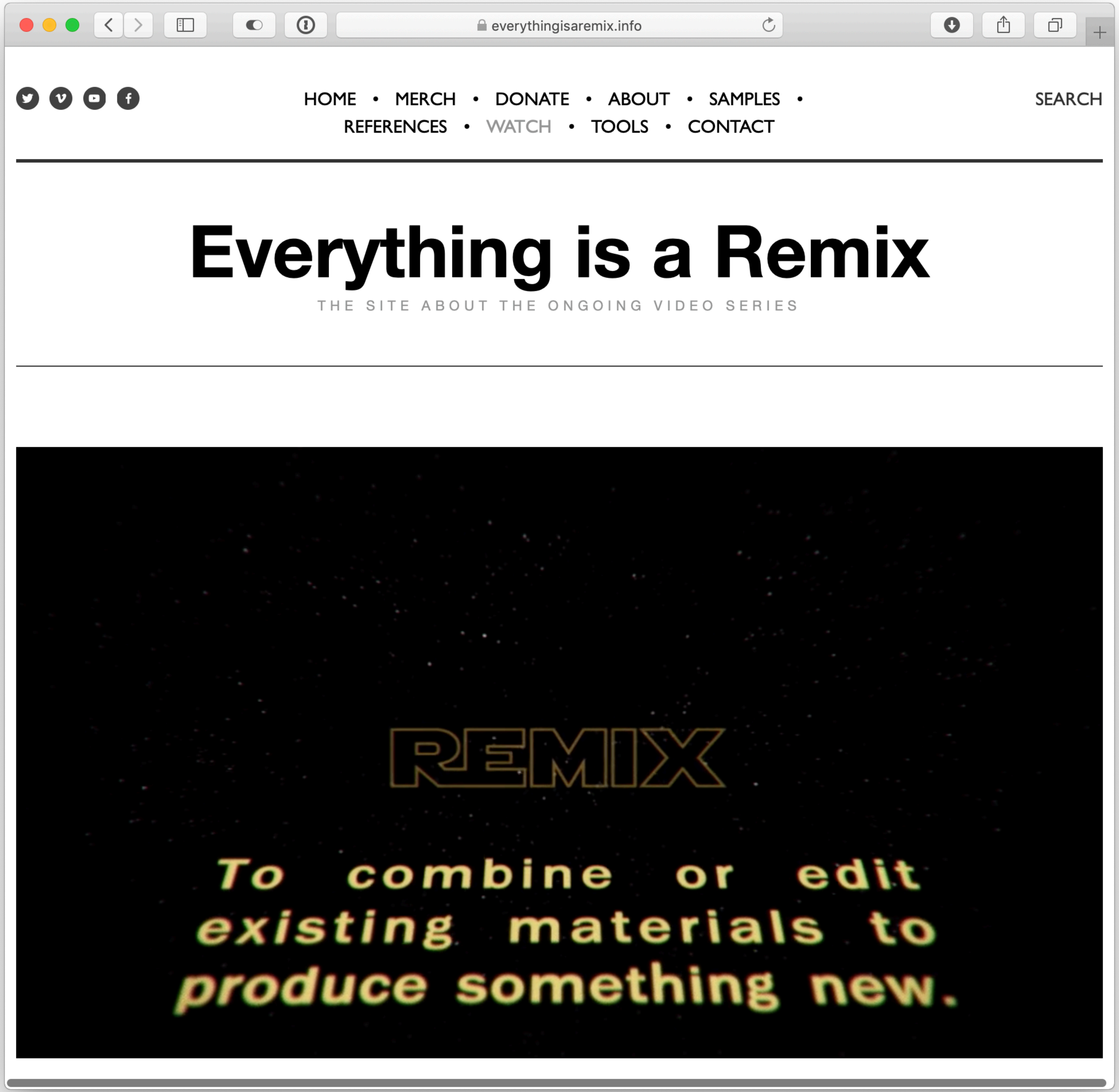
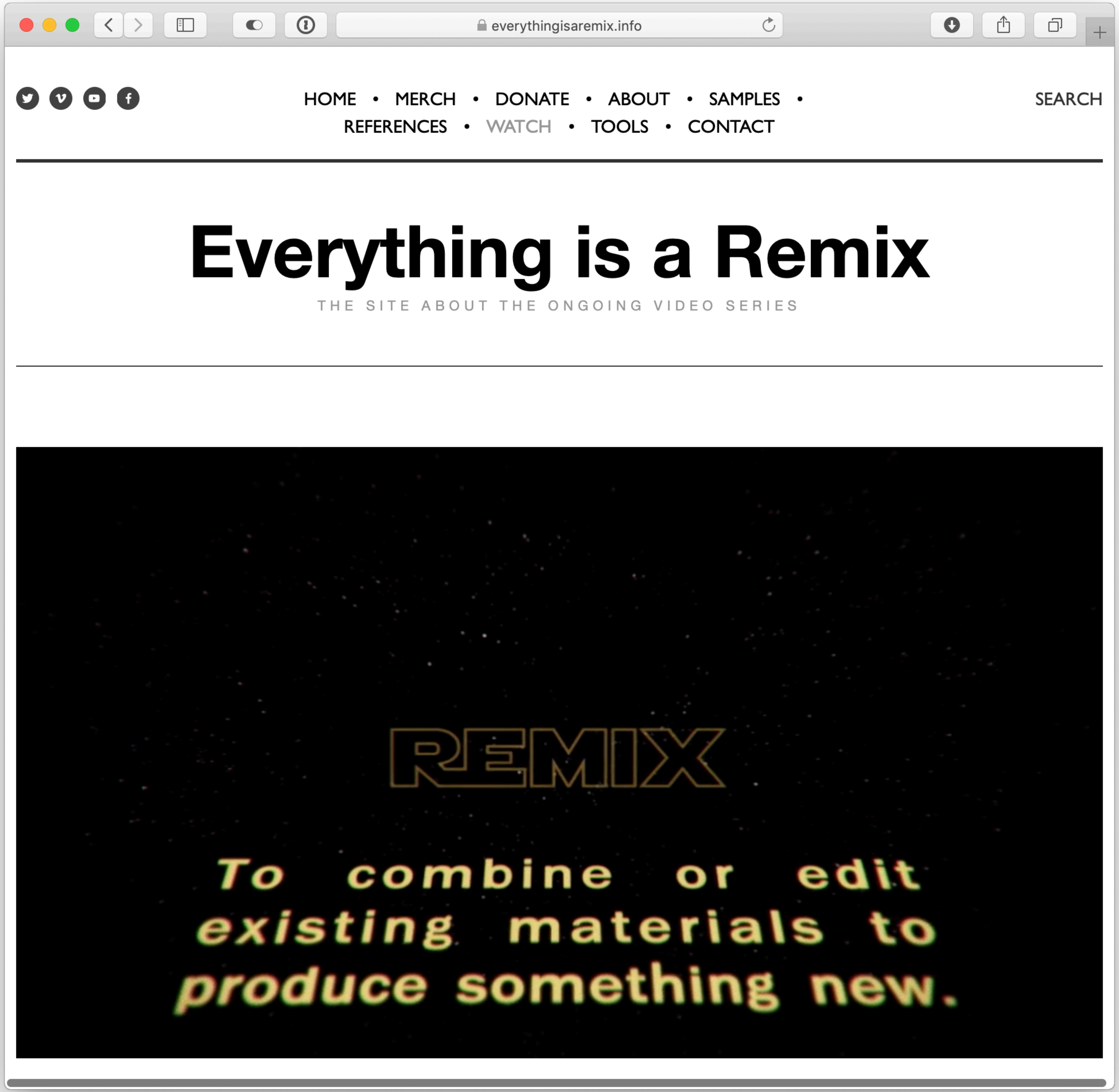

everythingisaremix.info
HOME • MERCH • DONATE • ABOUT • SAMPLES •
REFERENCES • WATCH • TOOLS • CONTACT
SEARCH
Everything is a Remix
THE SITE ABOUT THE ONGOING VIDEO SERIES
REMIX
To combine or edit existing materials to produce something new.



Five Decades of RT Literature

➔ A *rich* foundation!



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➔ A *rich* foundation!

No Need for Completely New Inventions

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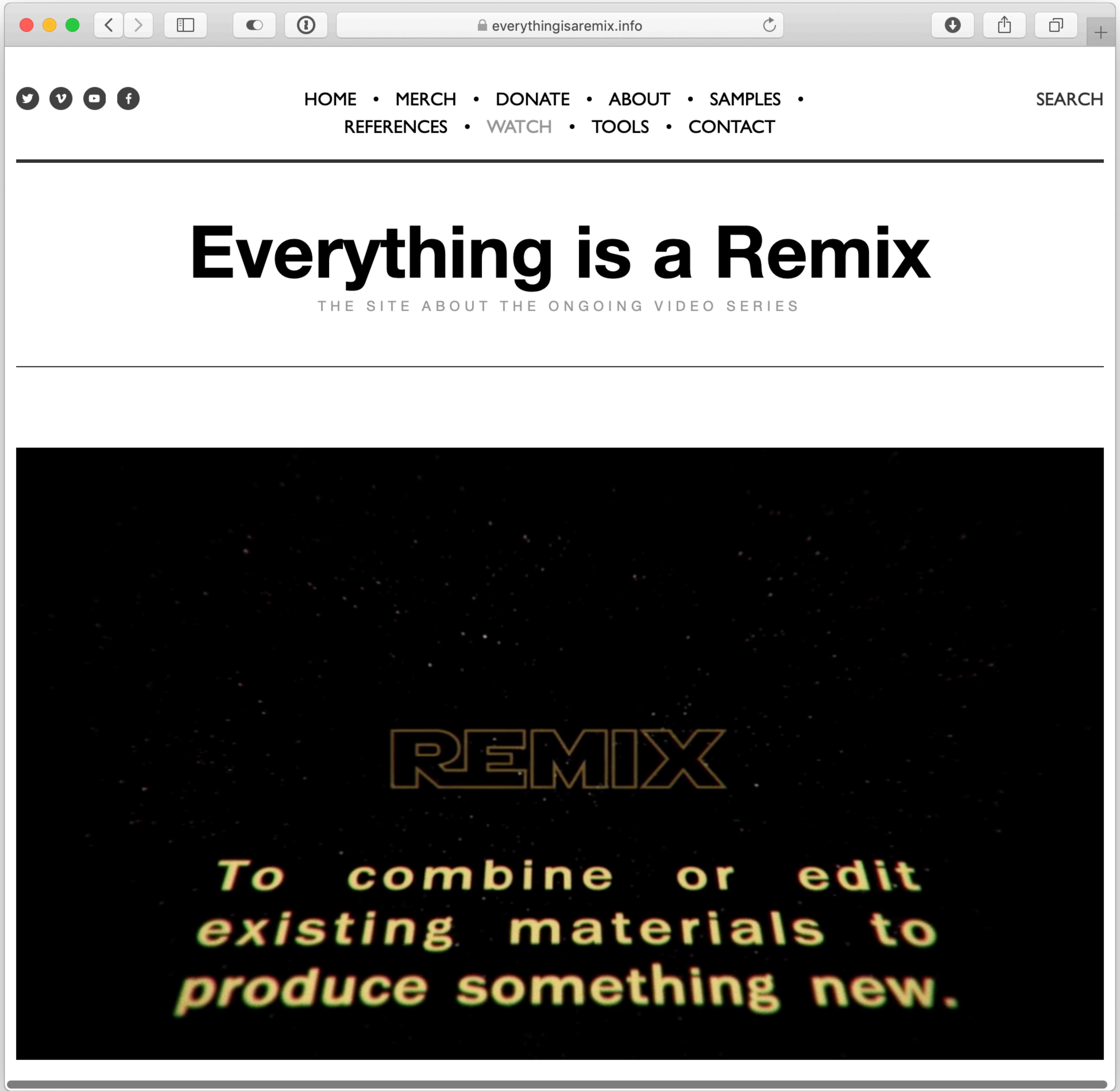

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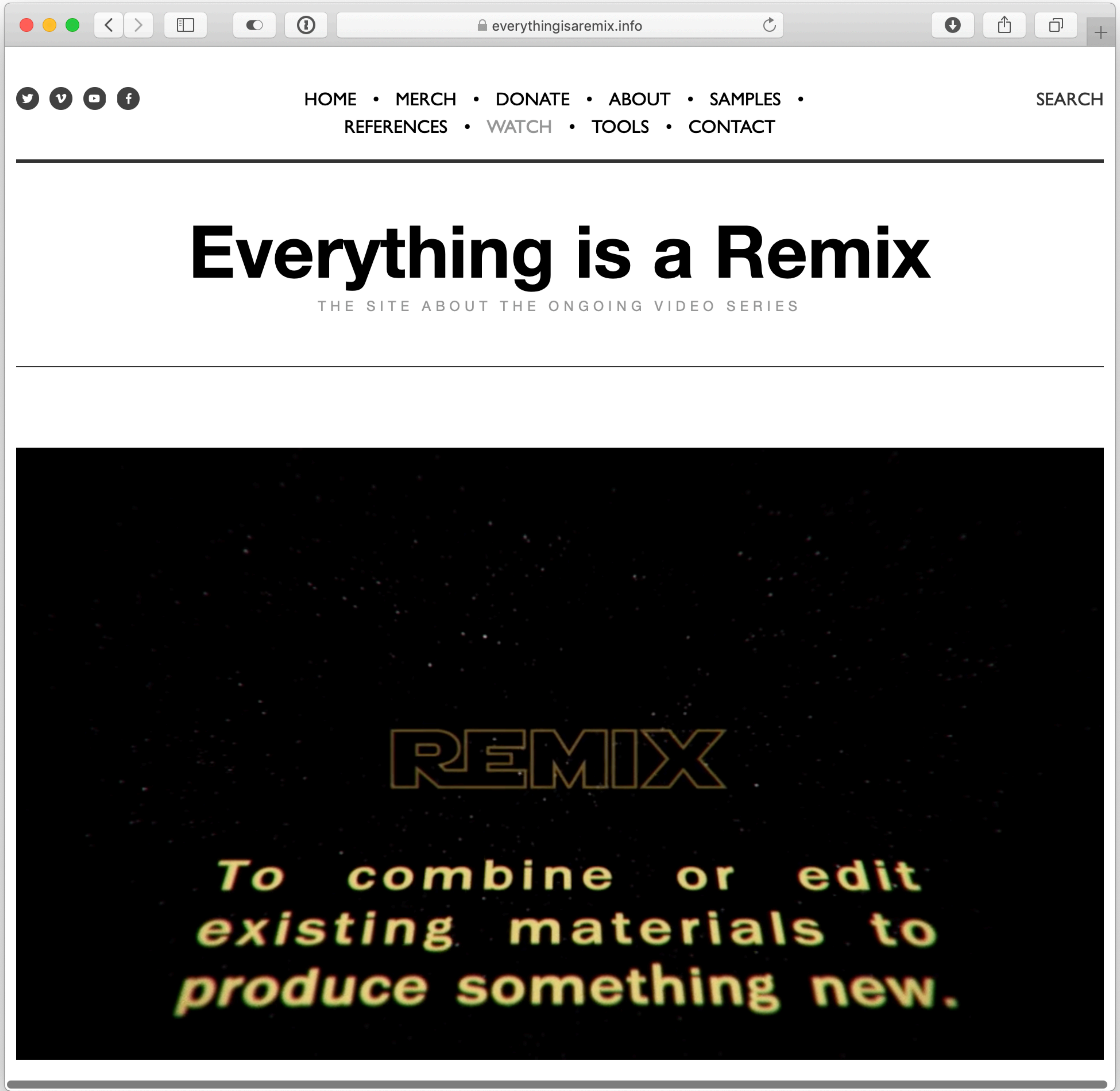

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(5) **trustworthy analysis**: verify analysis soundness with **machine-checked proofs** using the **Coq** proof assistant [*not discussed today*]

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Challenges

➔ Can one still build practical applications with reasonable effort on top of such a minimal, unconventional foundation?

➔ Massive engineering effort to get the system off the ground…

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automatically checkable timing and resource-allocation **goals**
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Challenges

➔ Need one-size-fits-all scheduling and synchronization policies

➔ Automatically map specified goals to efficient parameter choices

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Guaranteed Processor Share (GPS)

Fraction of a core (%)
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short-lived, nameless execution context (stack) + **run-to-completion semantics** (cannot suspend to wait)

- ➔ like callbacks or event handlers in flight
- ➔ always start at some entry point
- ➔ cannot wait
- ➔ cannot be referenced

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Only two ways for EJs to interact

`asynchronous_invoke(LDC::entry_point, GPS)` → **fork**

`synchronous_invoke(LDC::entry_point, GPS)` → **call-return semantics**

EXECUTION & PROGRAMMING MODEL

Hardware

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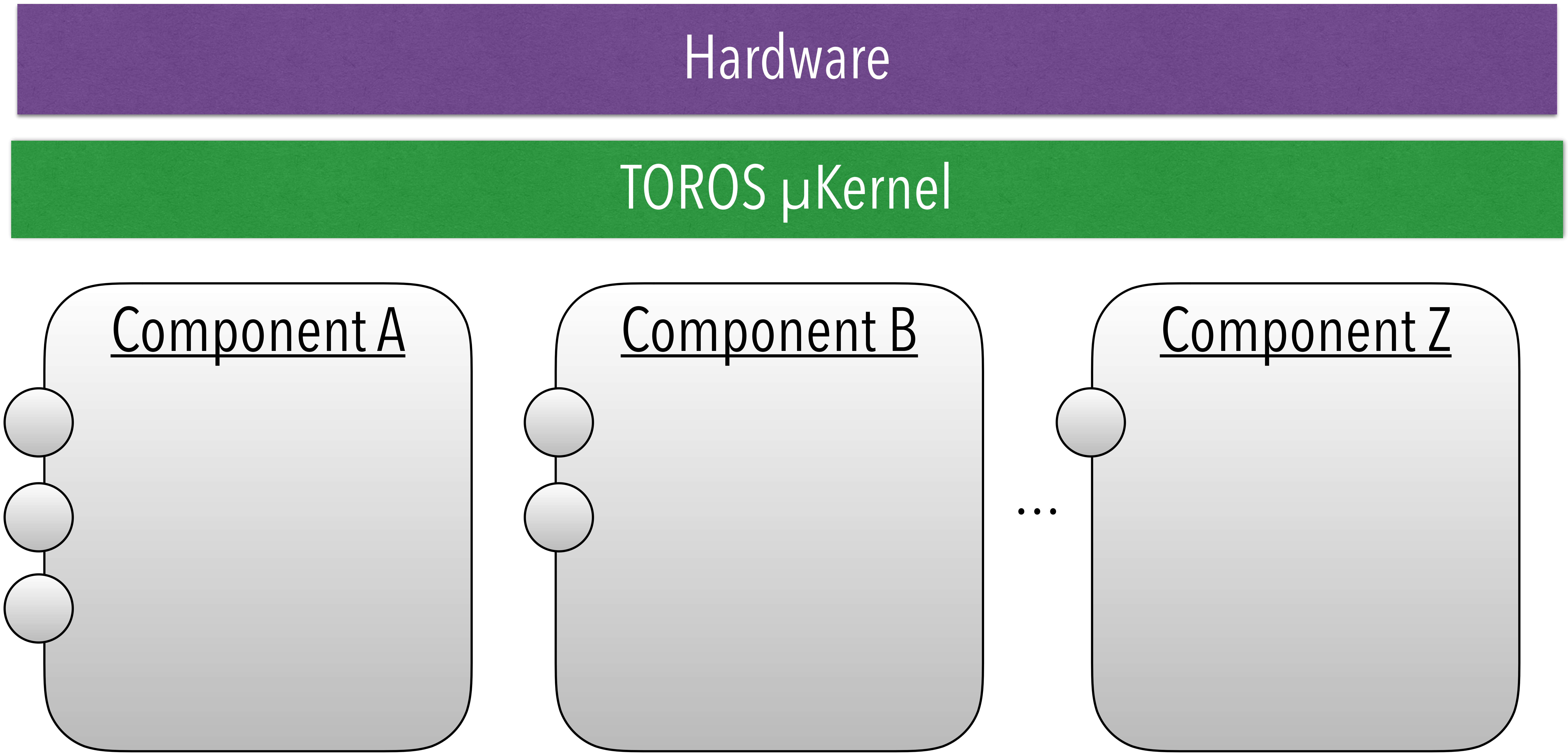
Hardware

TOROS µKernel

EXECUTION & PROGRAMMING MODEL



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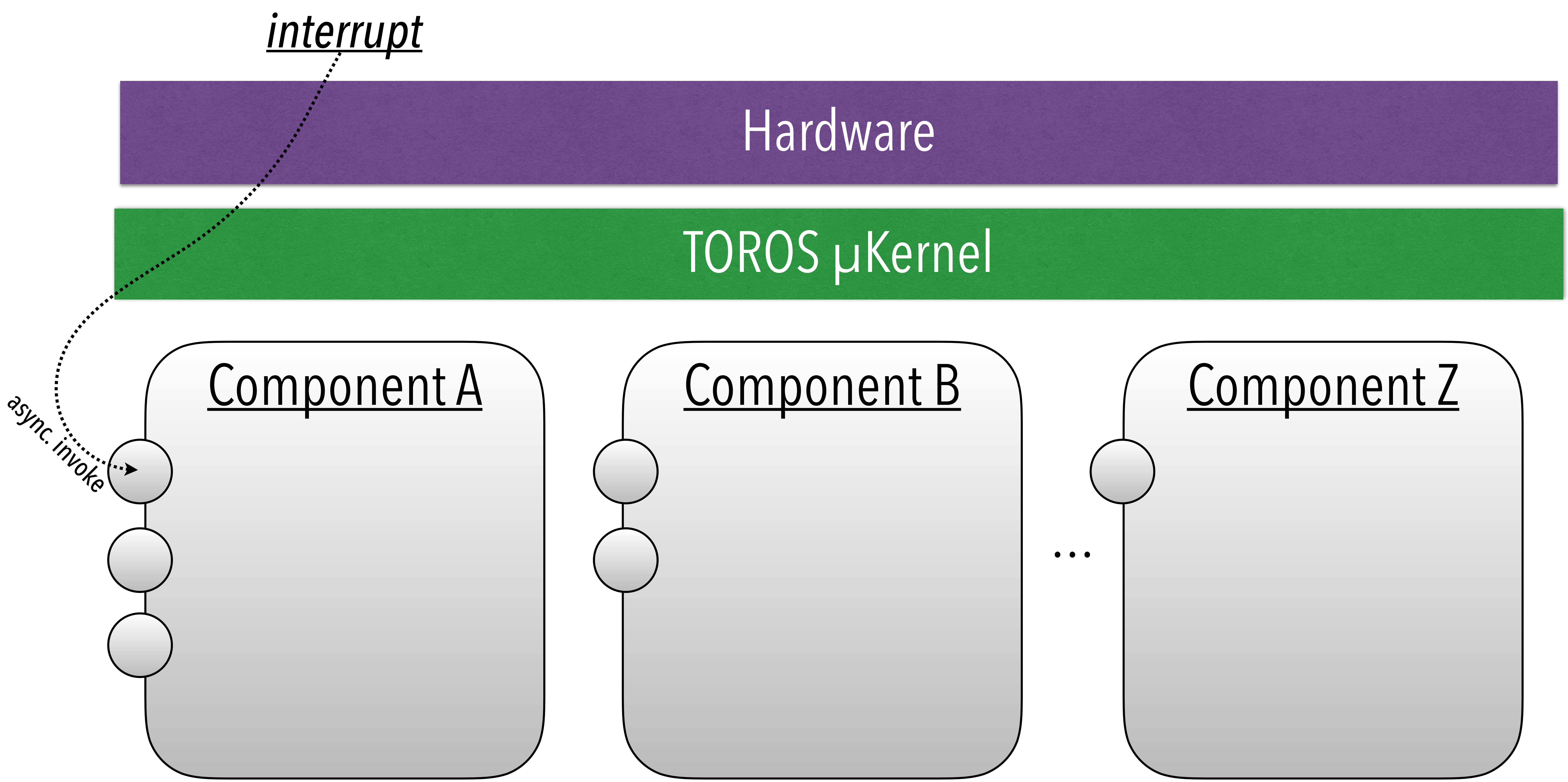

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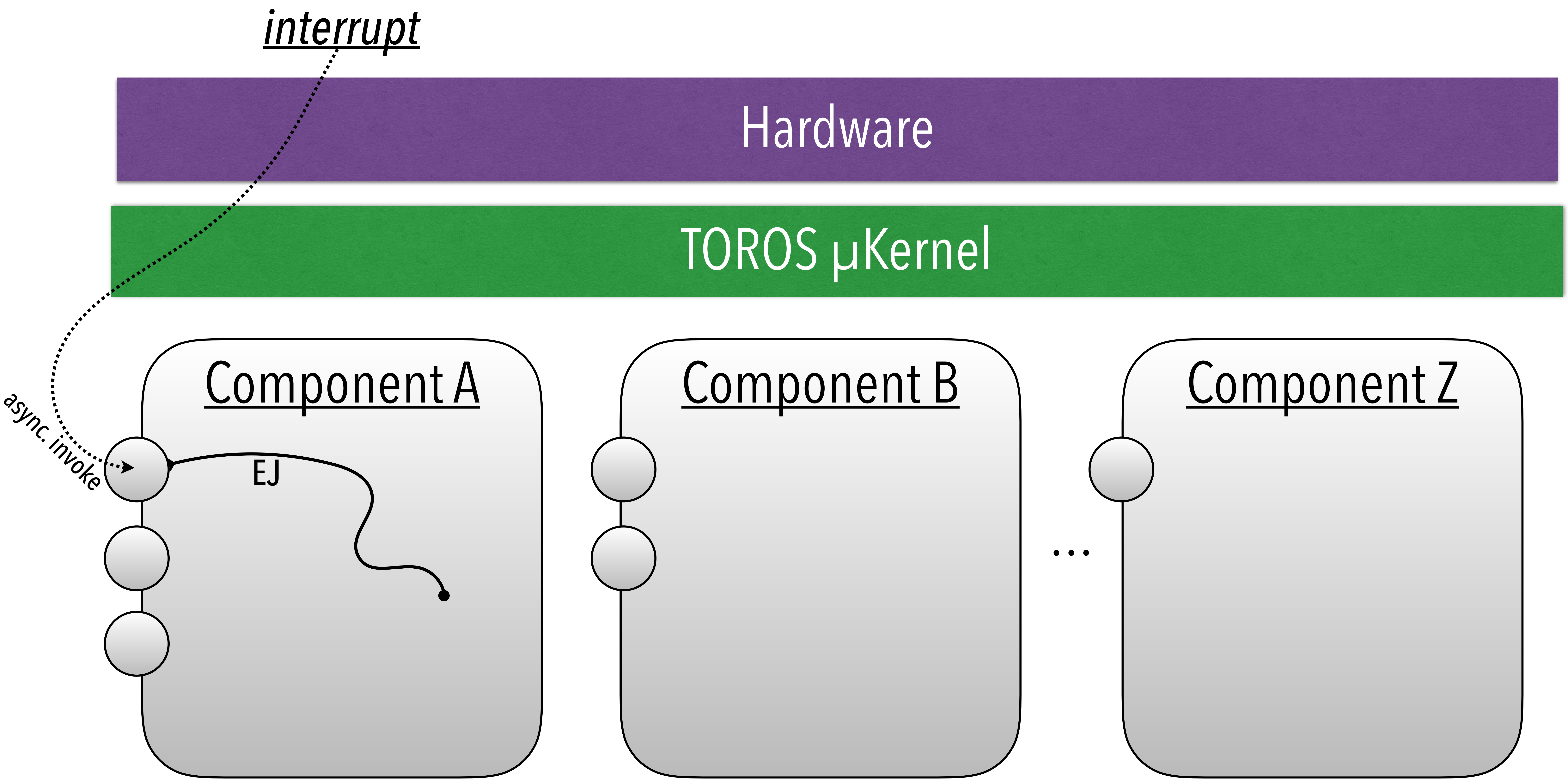

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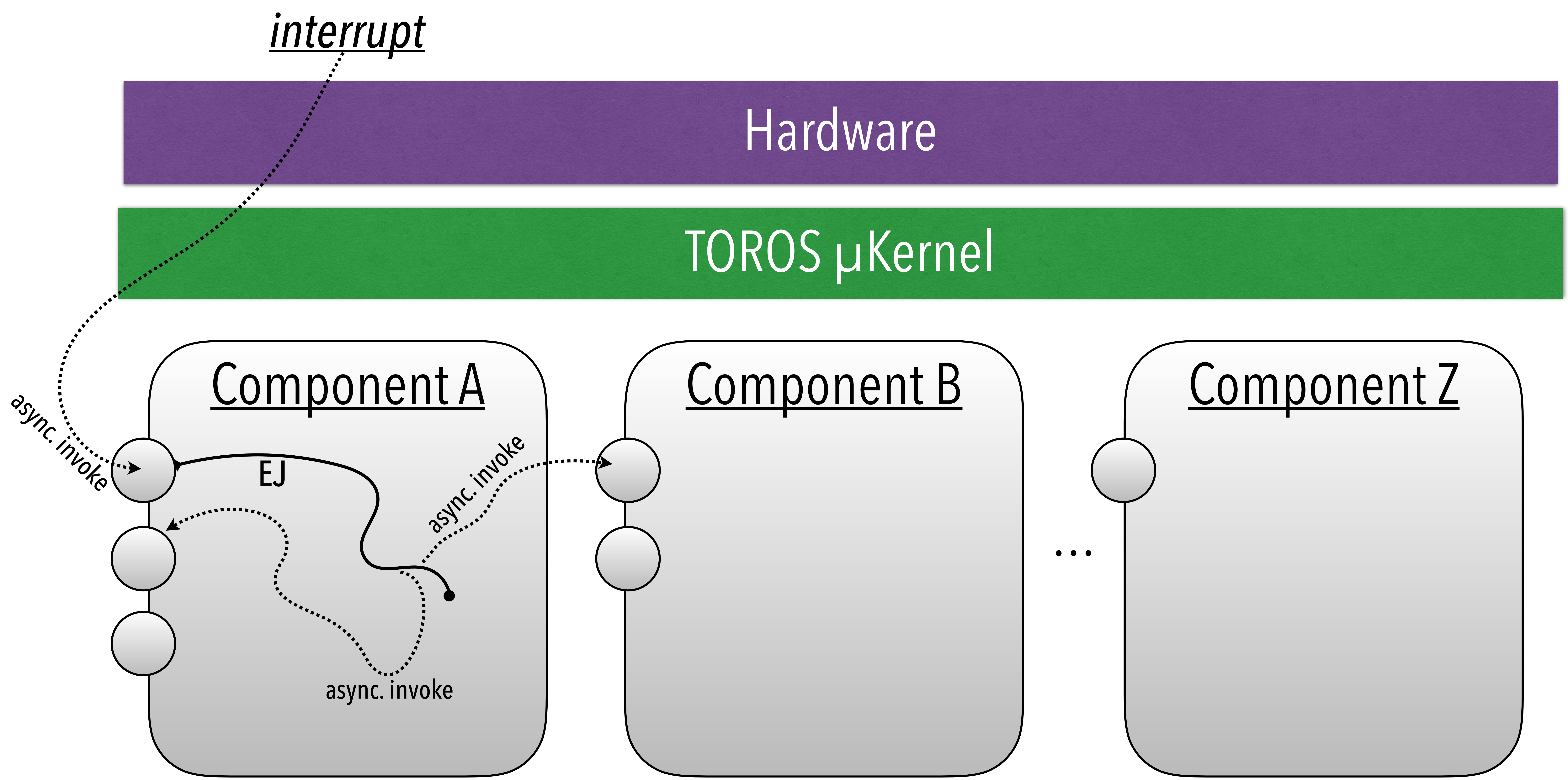

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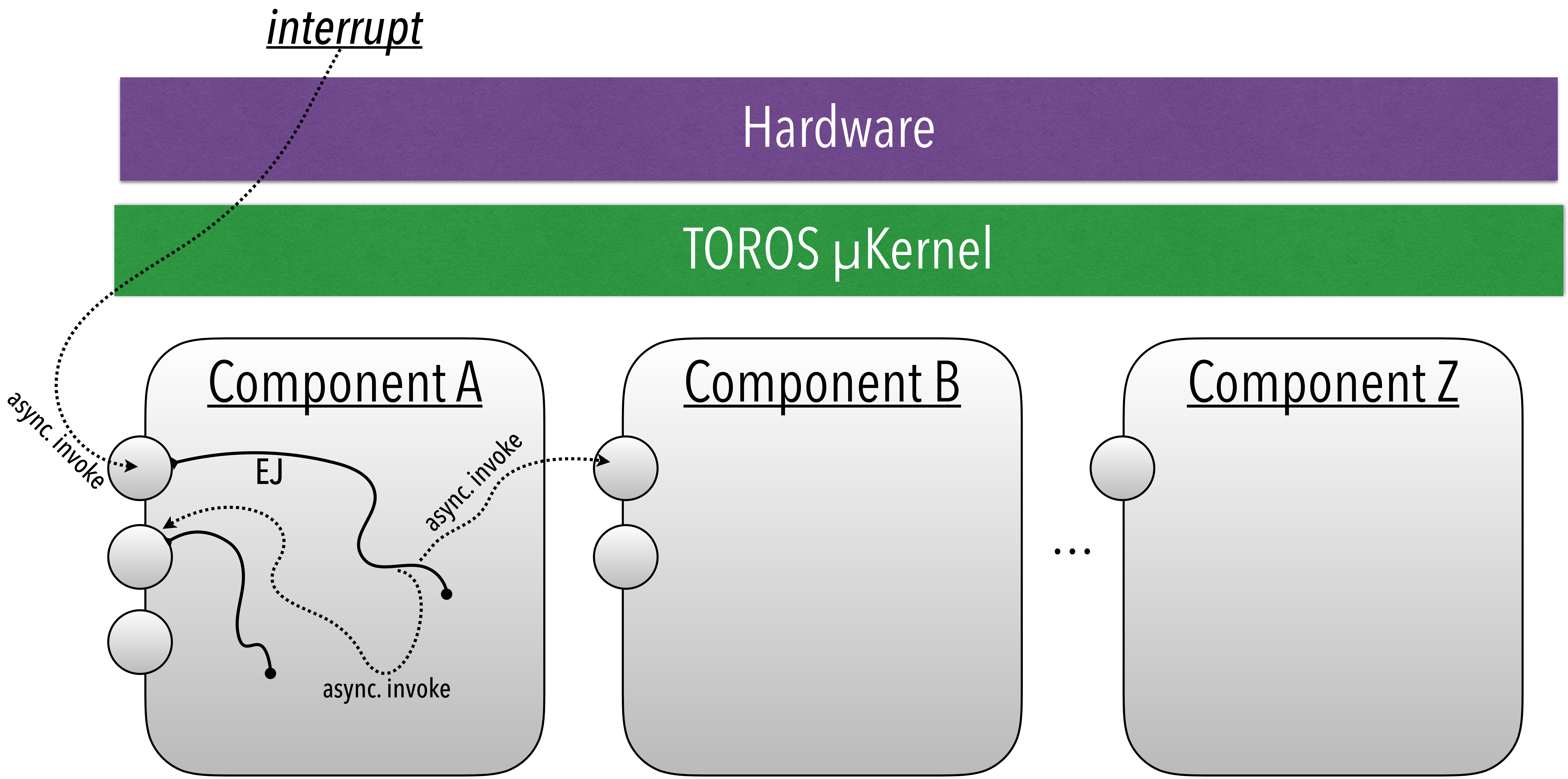

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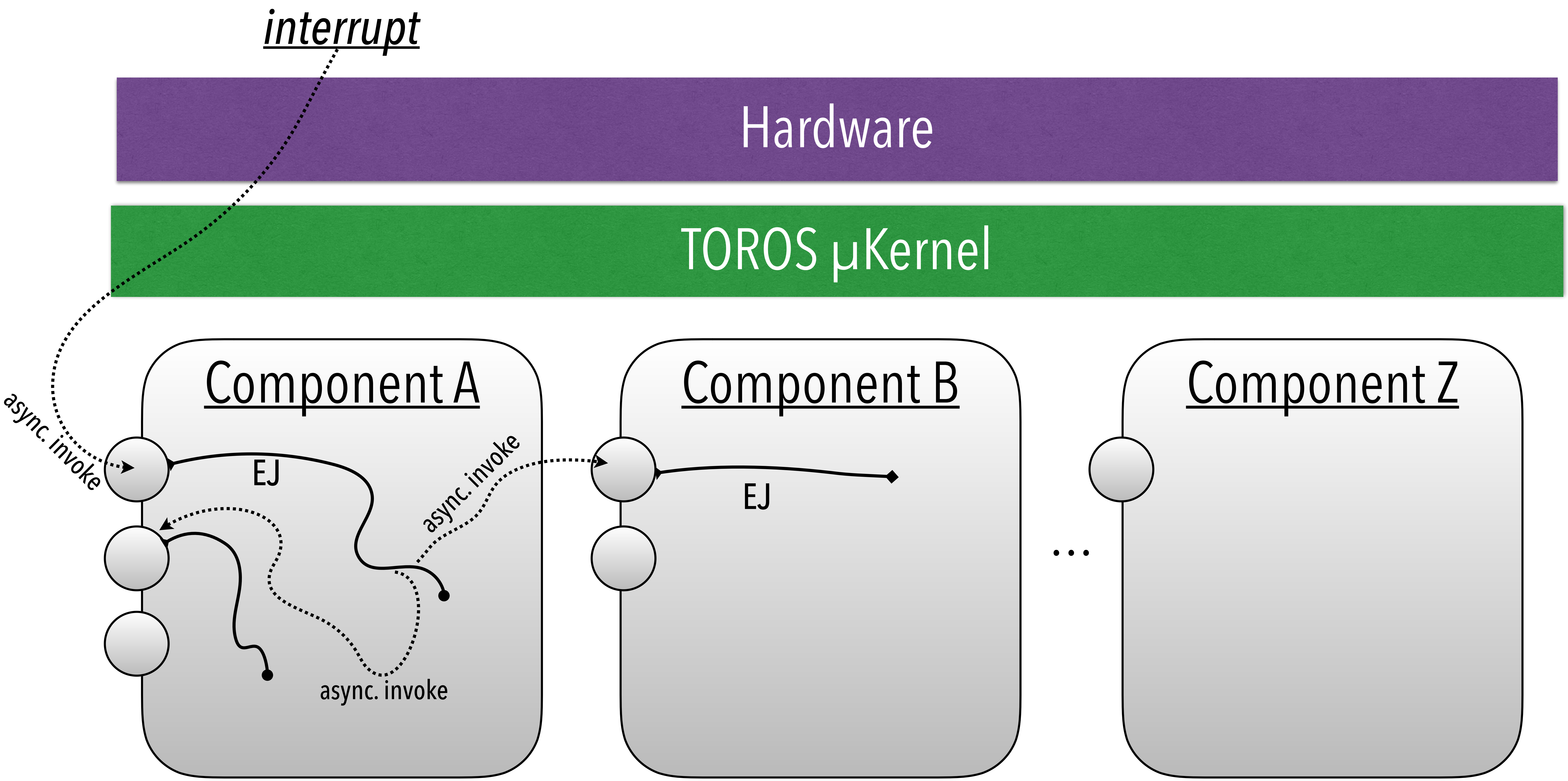

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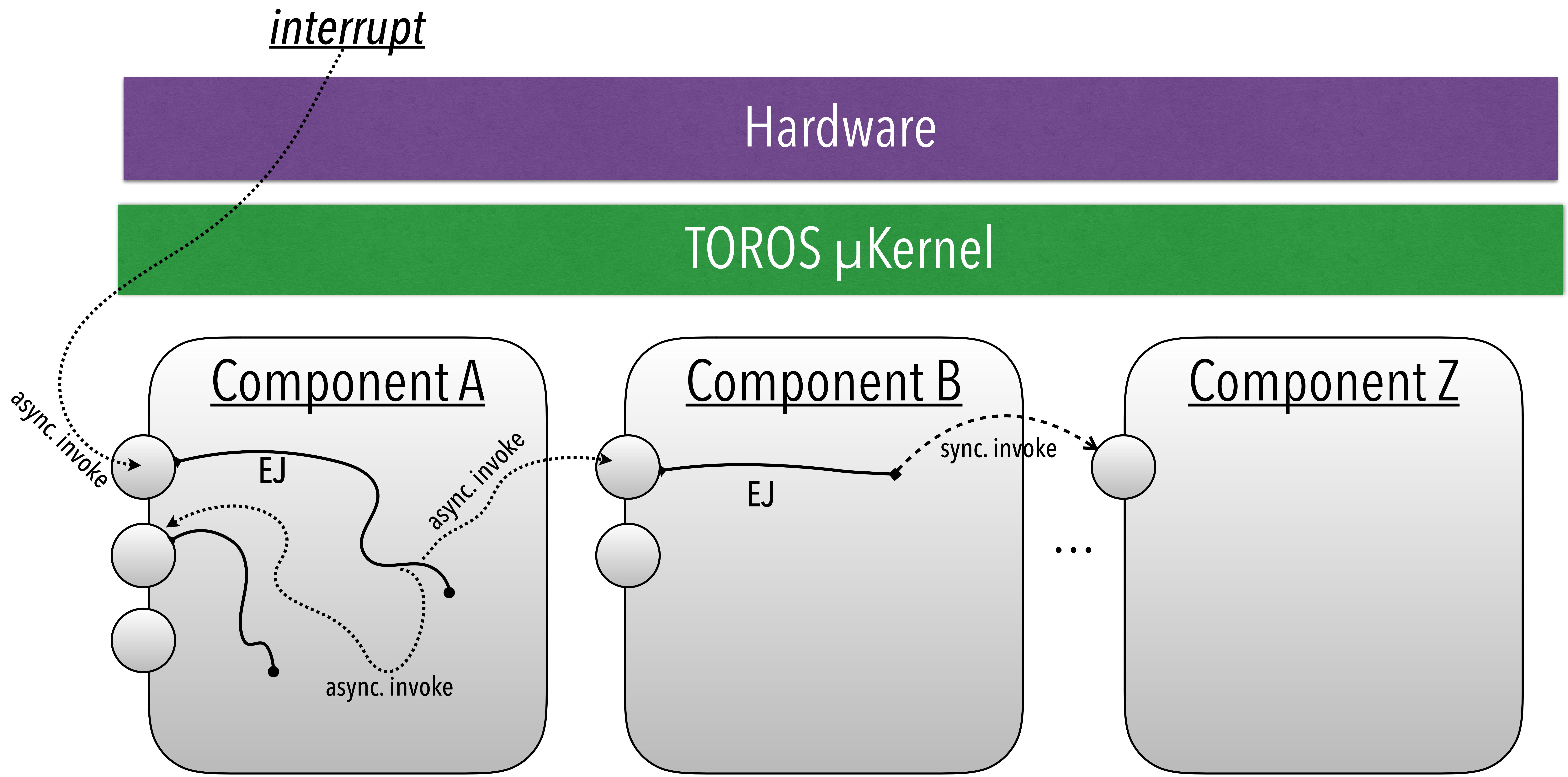

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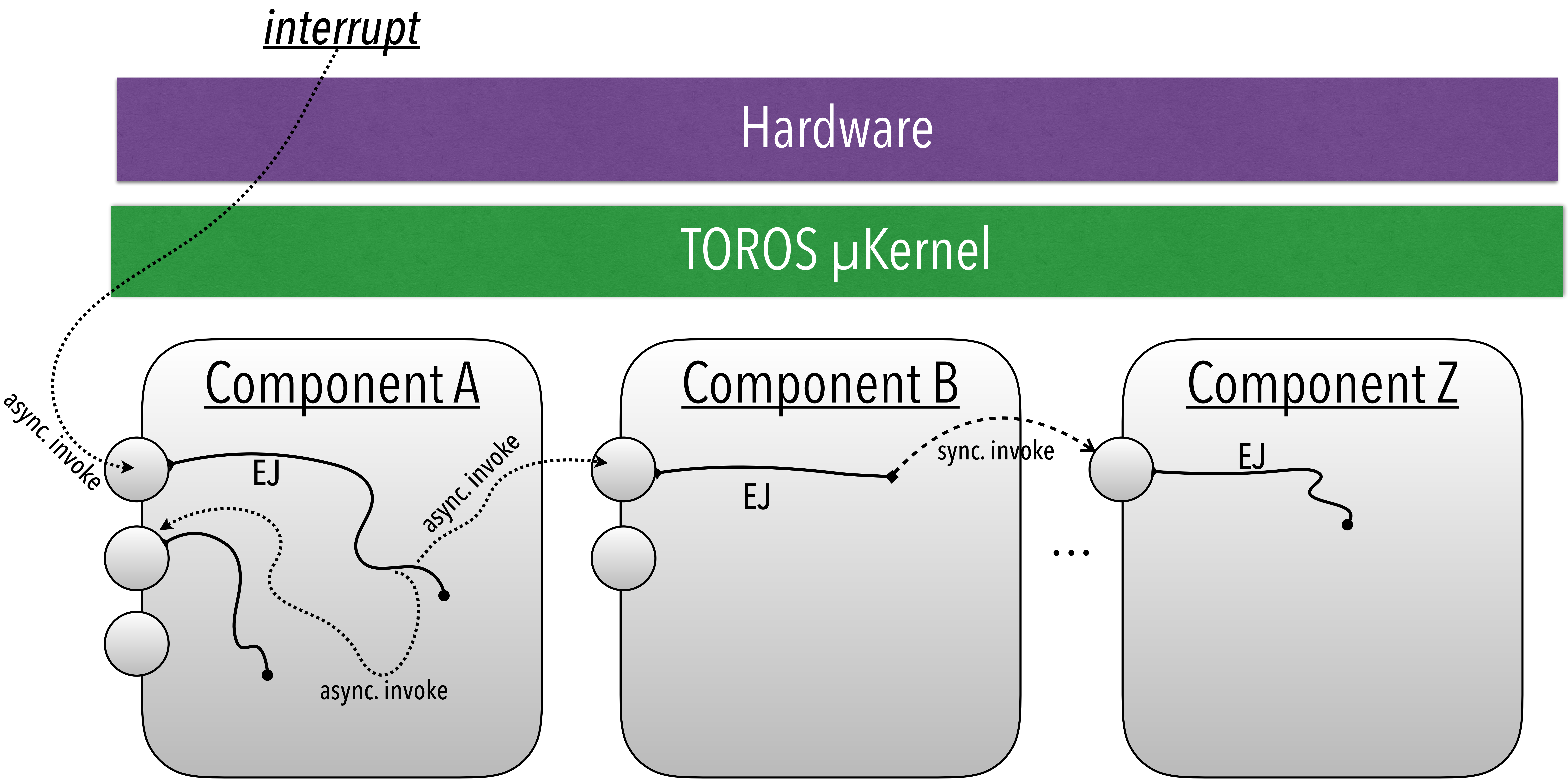

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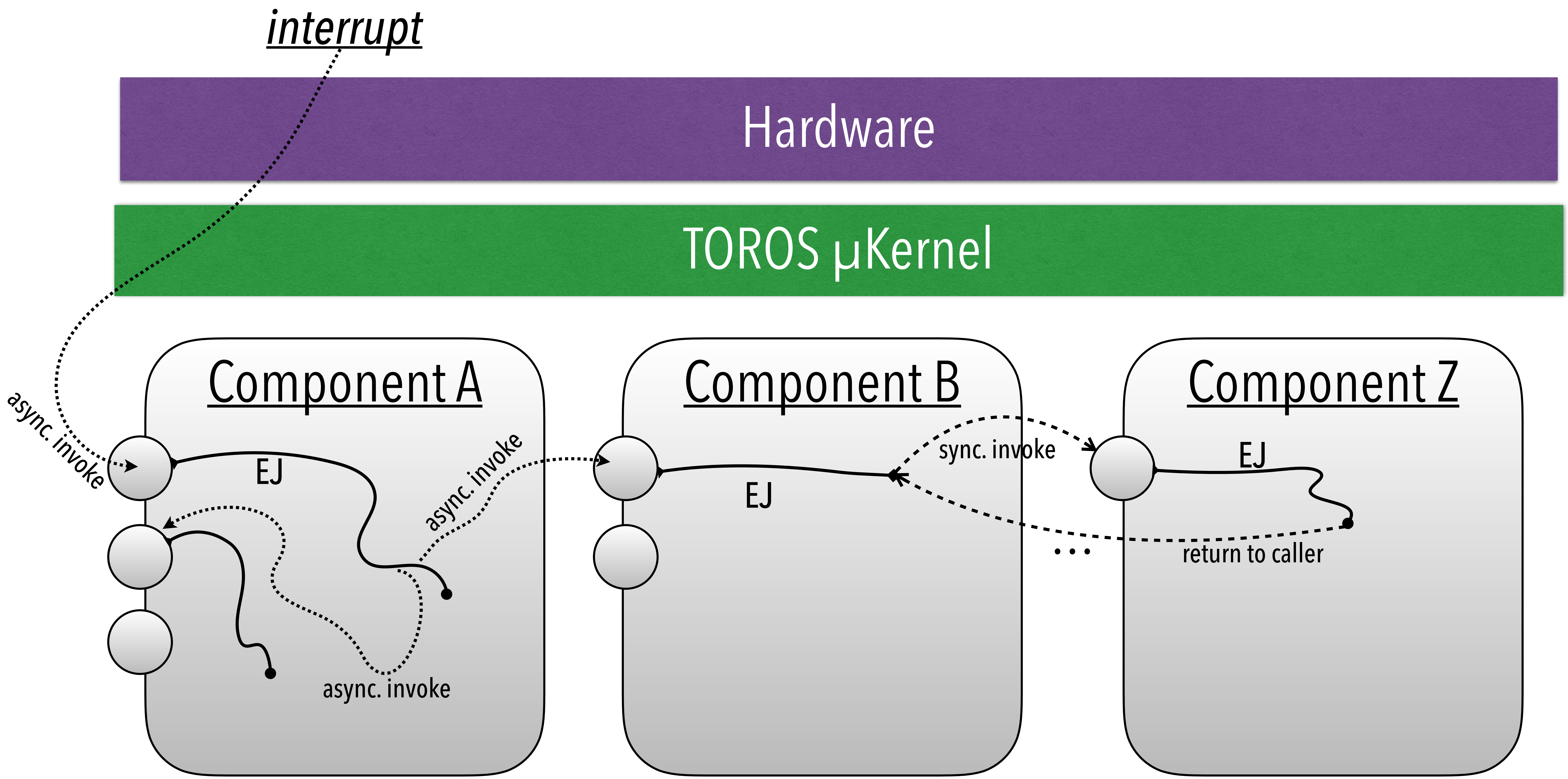

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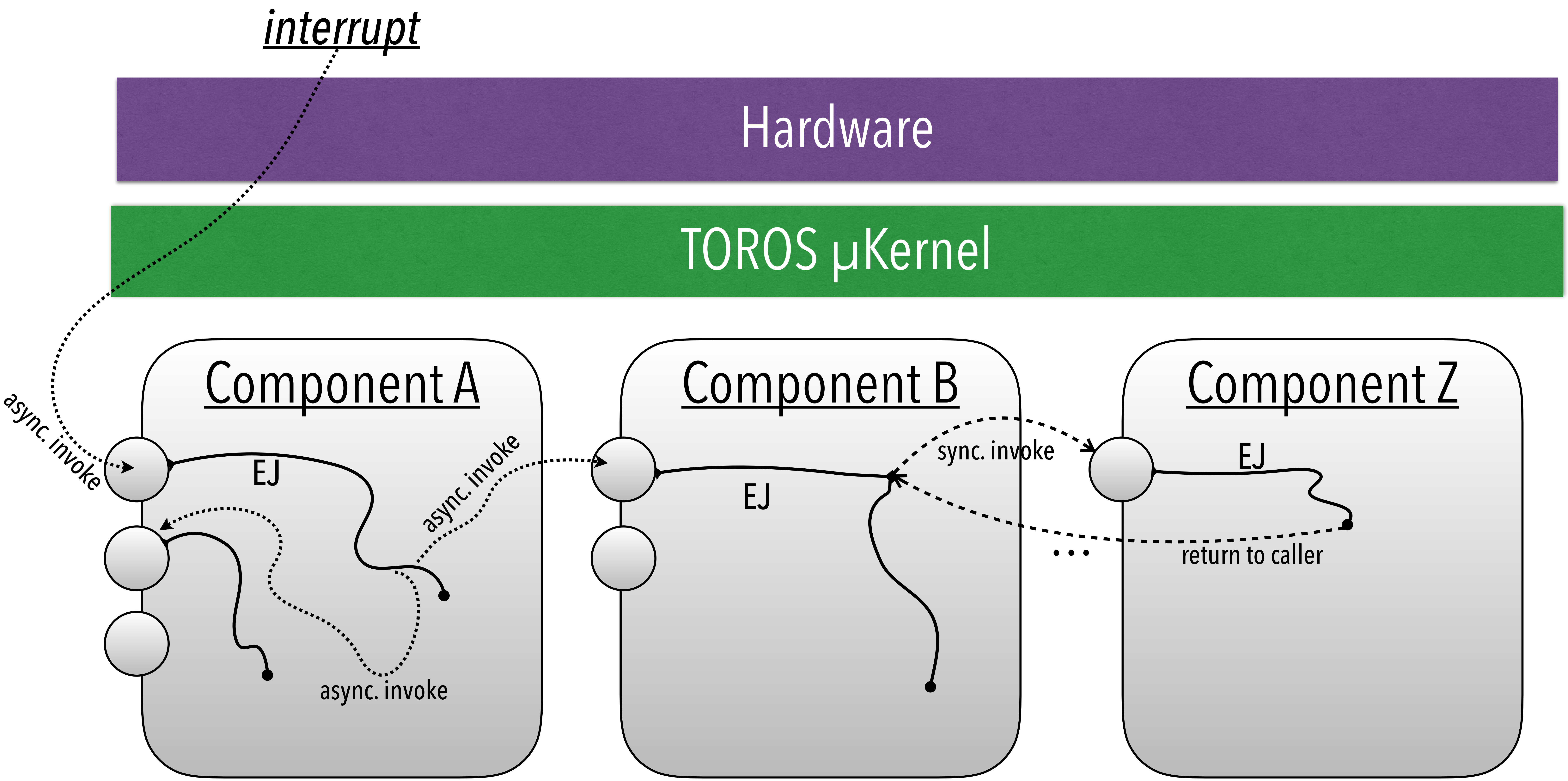

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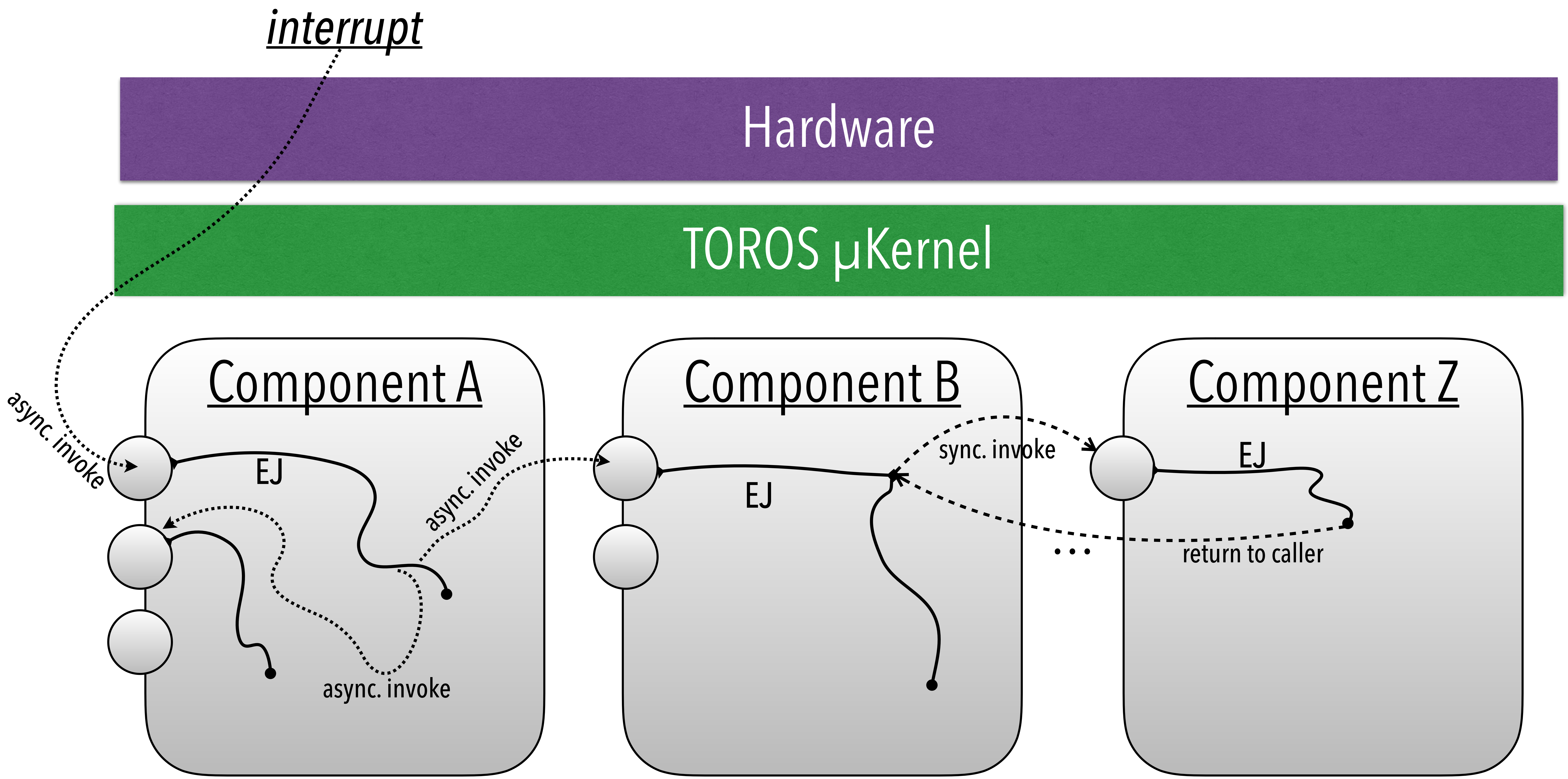

➔ event-driven / continuation-based / actor-like programming model

microkernel philosophy	vs	**opinionated design**
policy freedom		*freedom from choice*

<u>microkernel philosophy</u>

policy freedom

vs

<u>opinionated design</u>

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Aim for **maximal flexibility**: under no circumstance hardcode any policy into the OS.

The application developer knows best.

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L4 & Composite — Linux, RTEMS, FreeRTOS… — TOROS

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Do not measure WCETs!

We can trace percentiles (< 100) and (non-)correlations with high & quantifiable confidence in bounded space.

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Desired Guarantee: "Margin to Cliff" instead of "Yes/No"

"an increase in execution time by X% has no ill effects with probability at least Y"

CONCLUSION

European Research Council
Established by the European Commission

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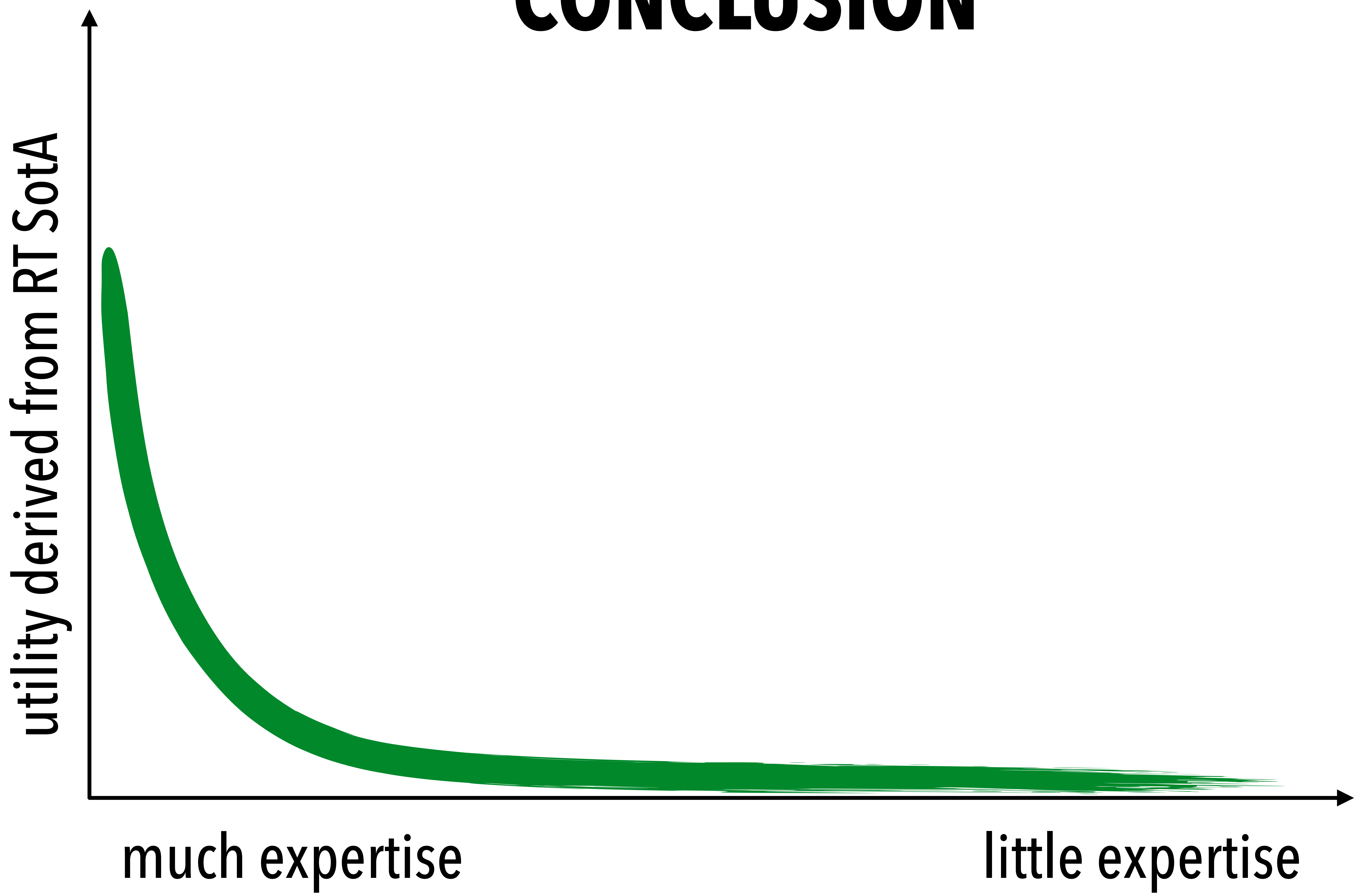
utility derived from RT SotA
much expertise
little expertise

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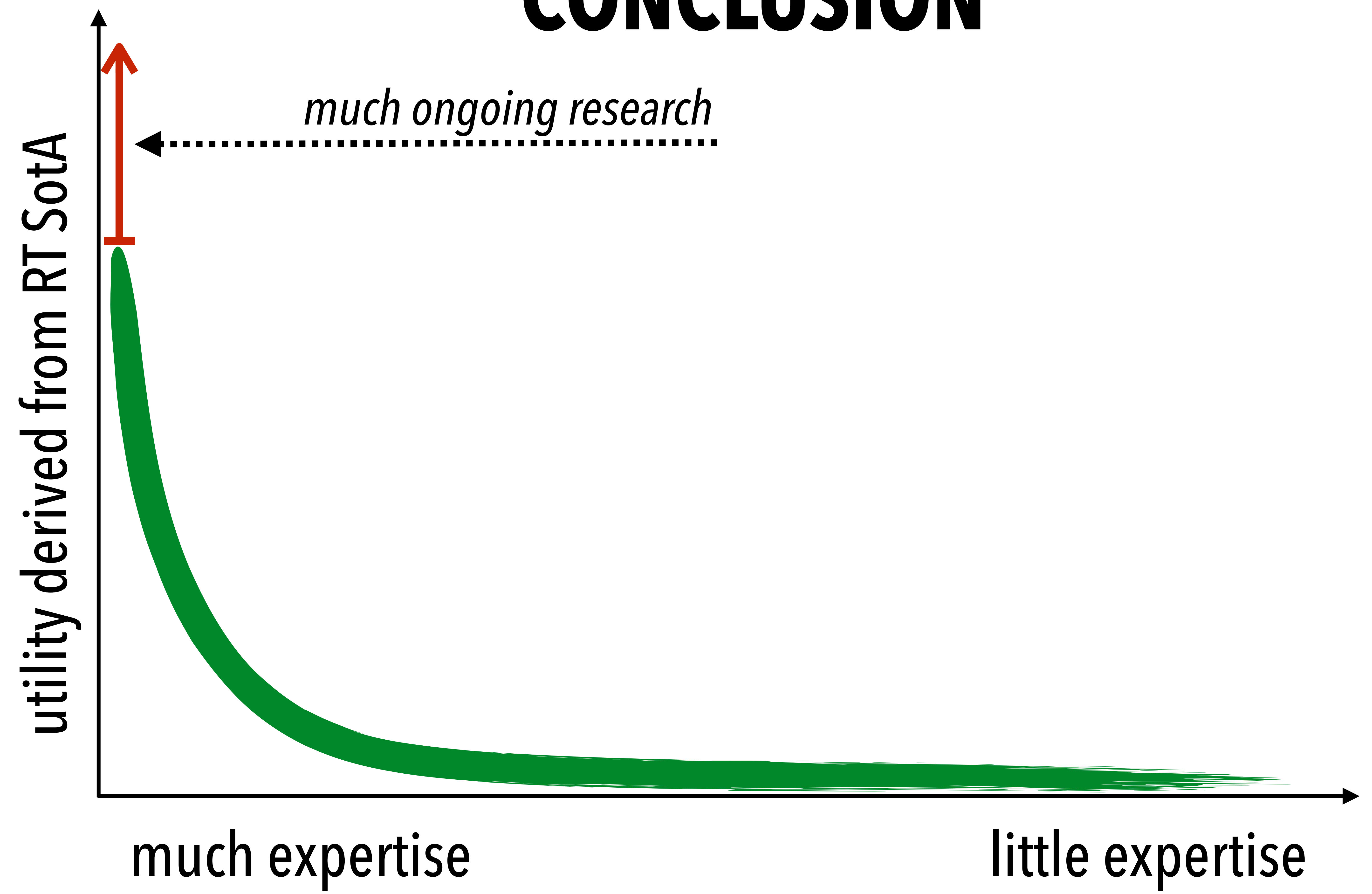

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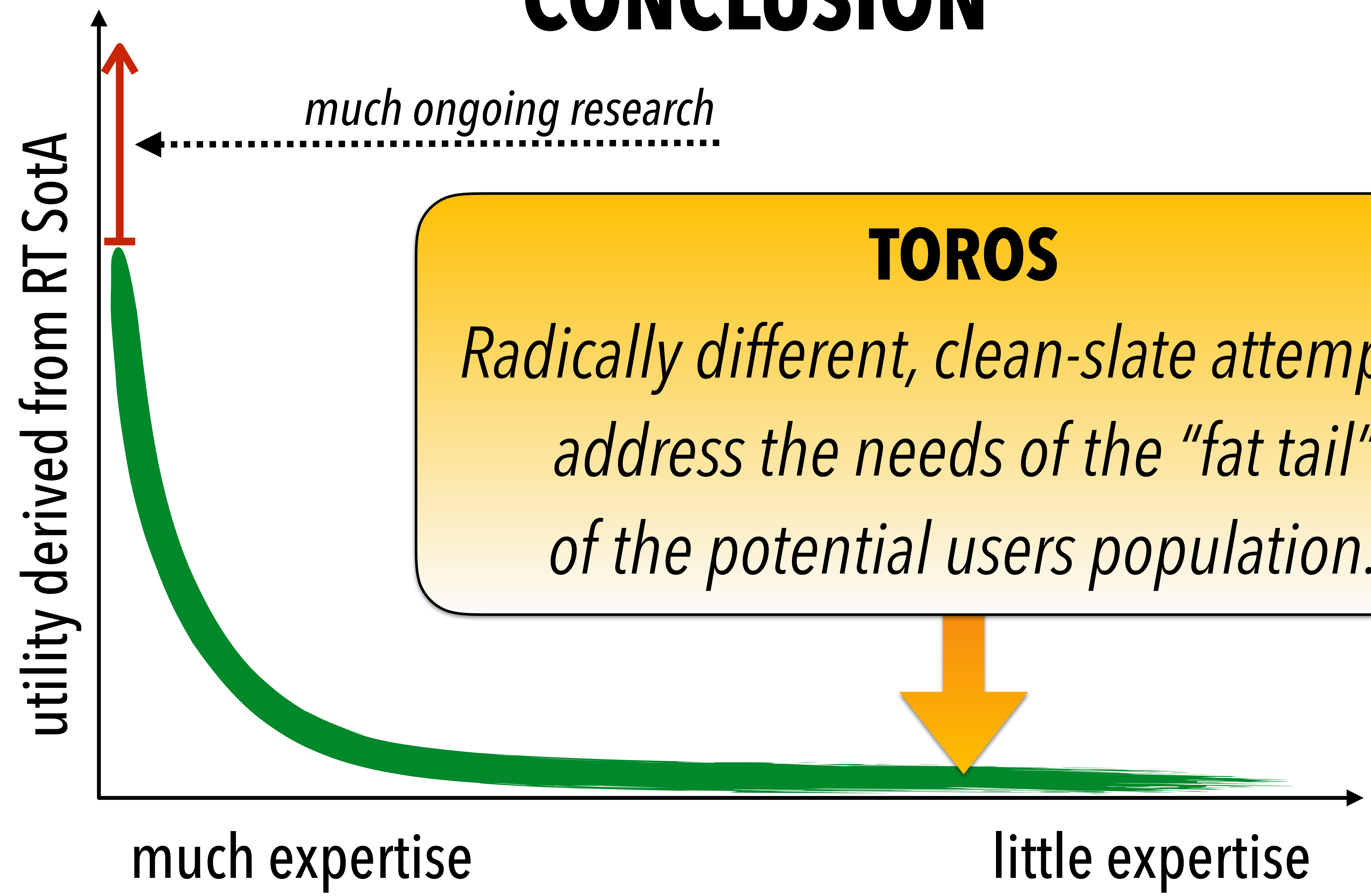

TOROS

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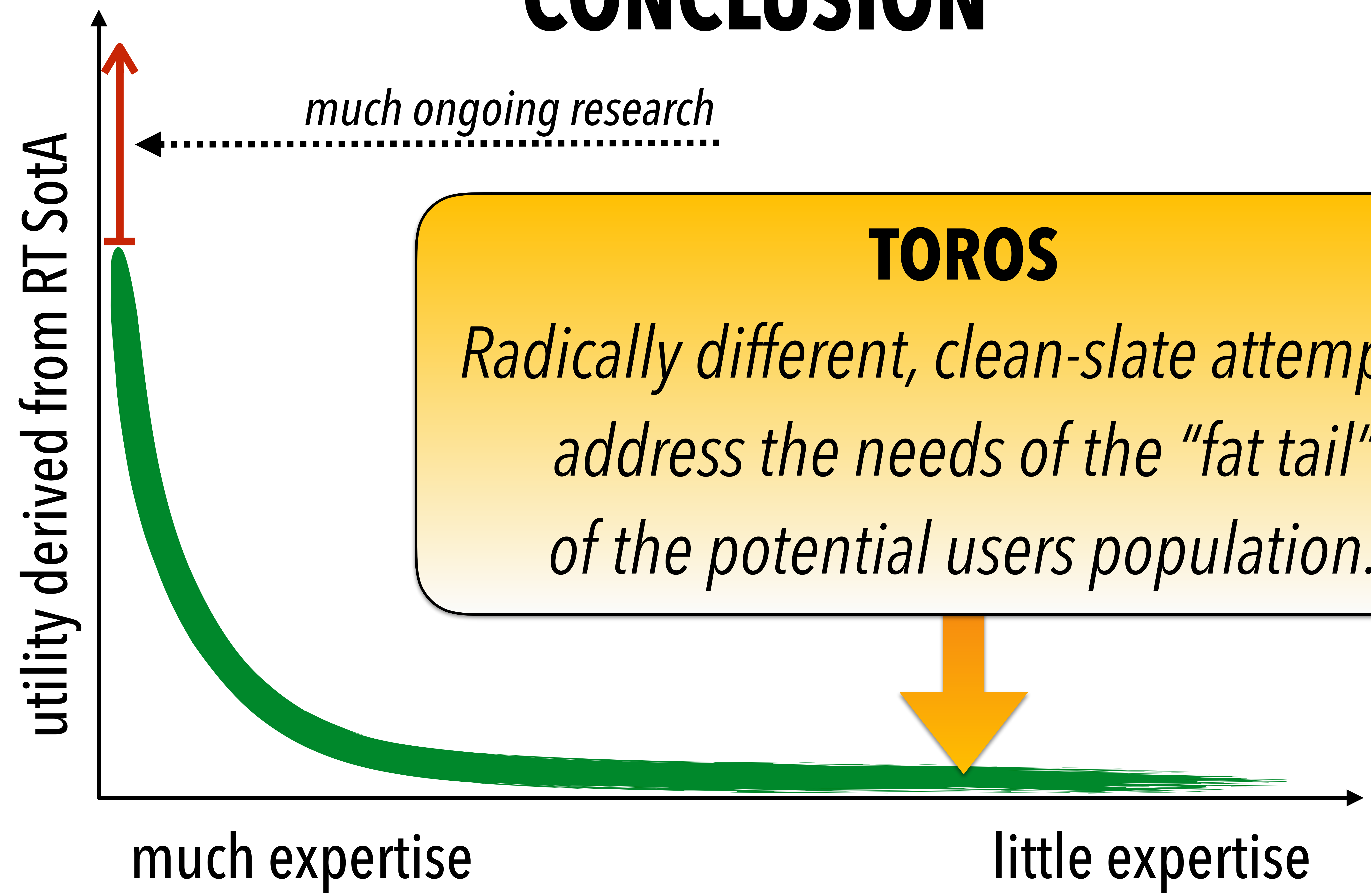

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