Gdev: First-Class GPU Resource Management in the Operating System

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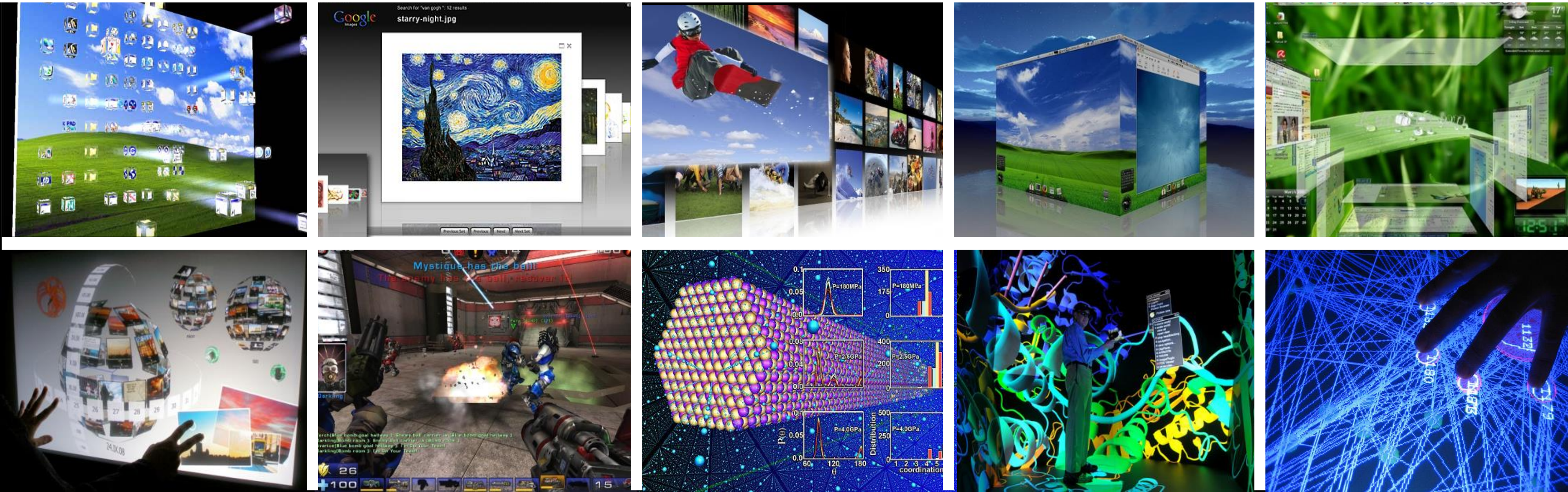
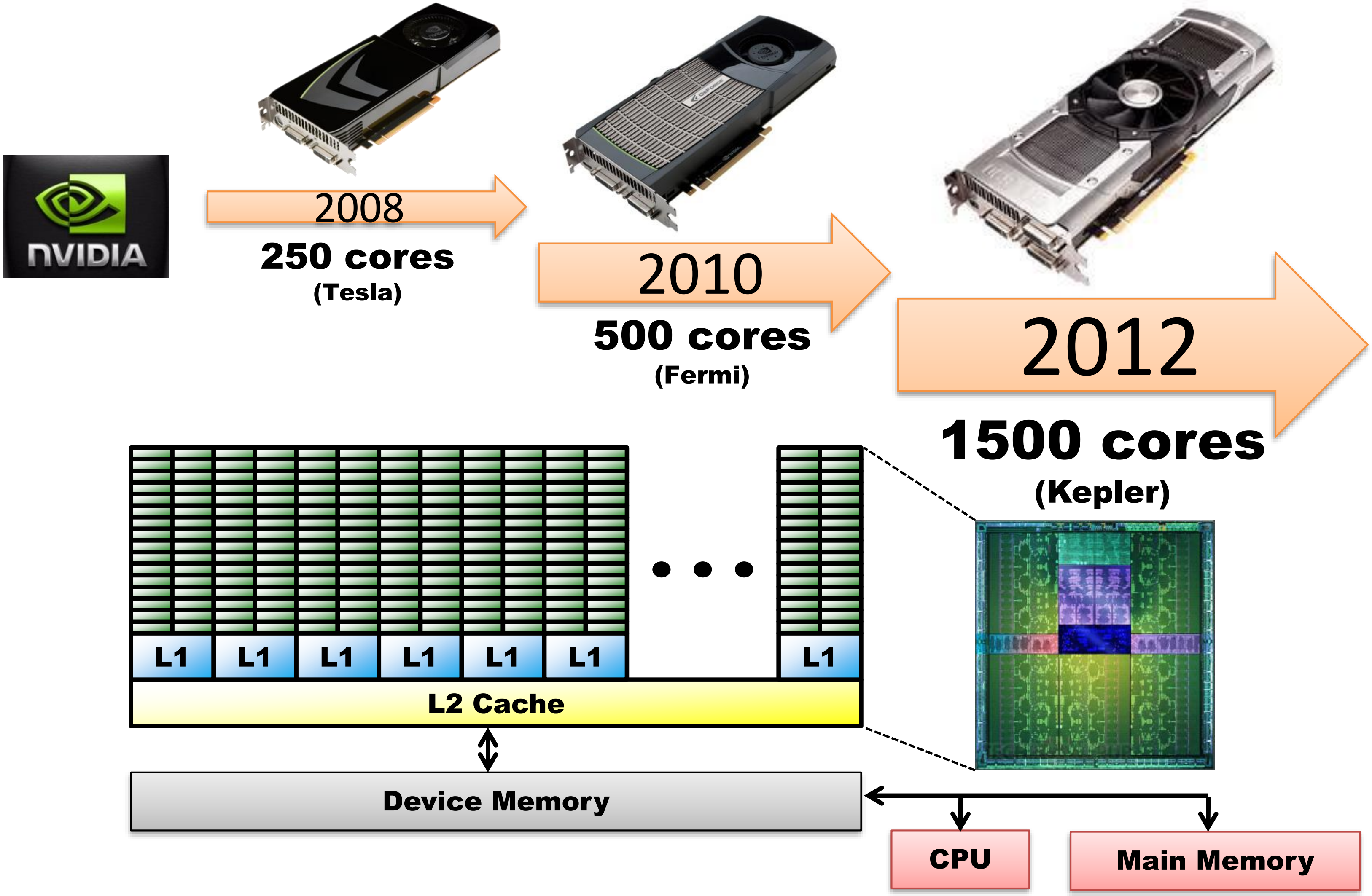
UC Santa Cruz



GPUs embrace “many cores”.

Graphics Processing Unit (GPU)



2008

250 cores

(Tesla)

2010

500 cores

(Fermi)

2012

1500 cores

(Kepler)

L1 **L1** **L1** **L1** **L1** **L1** • • • **L1**

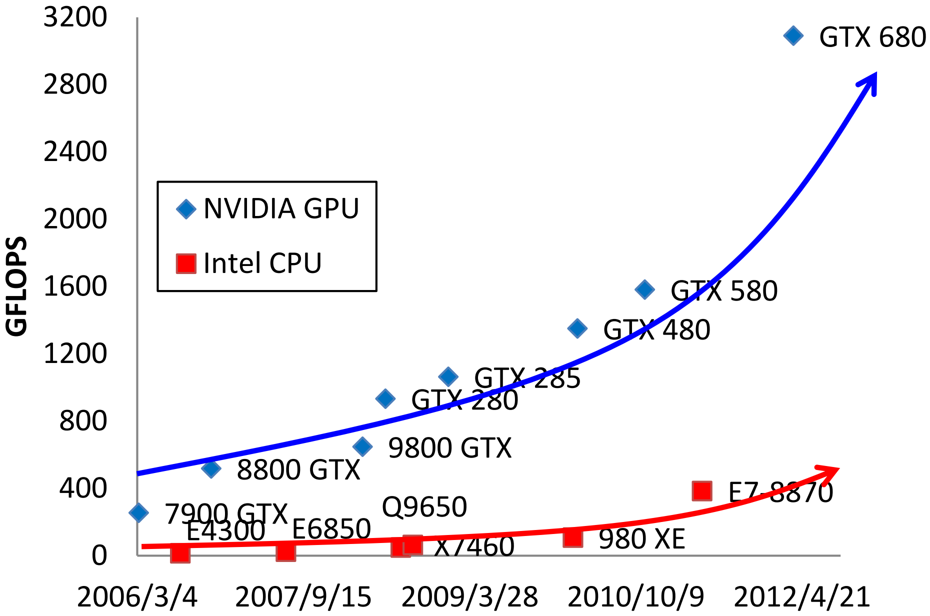
L2 Cache

Device Memory

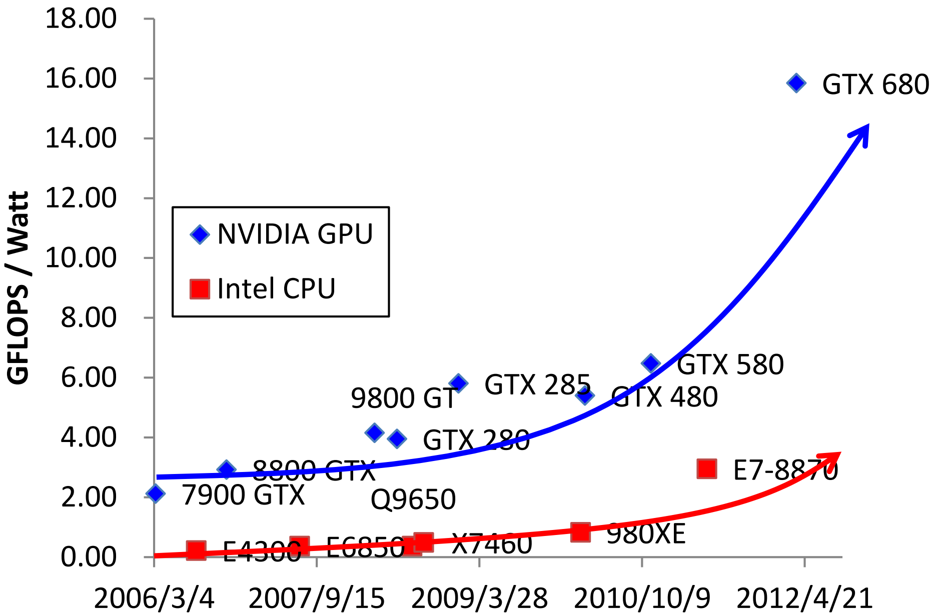
CPU

Main Memory

Performance Trend

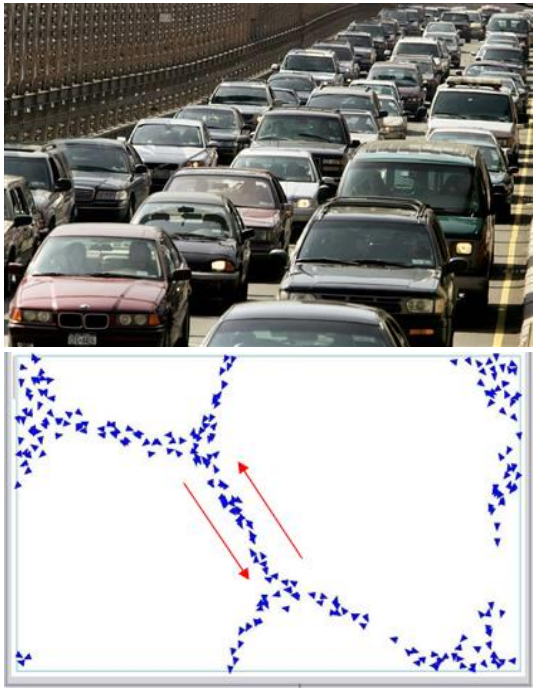


Single Precision Performance

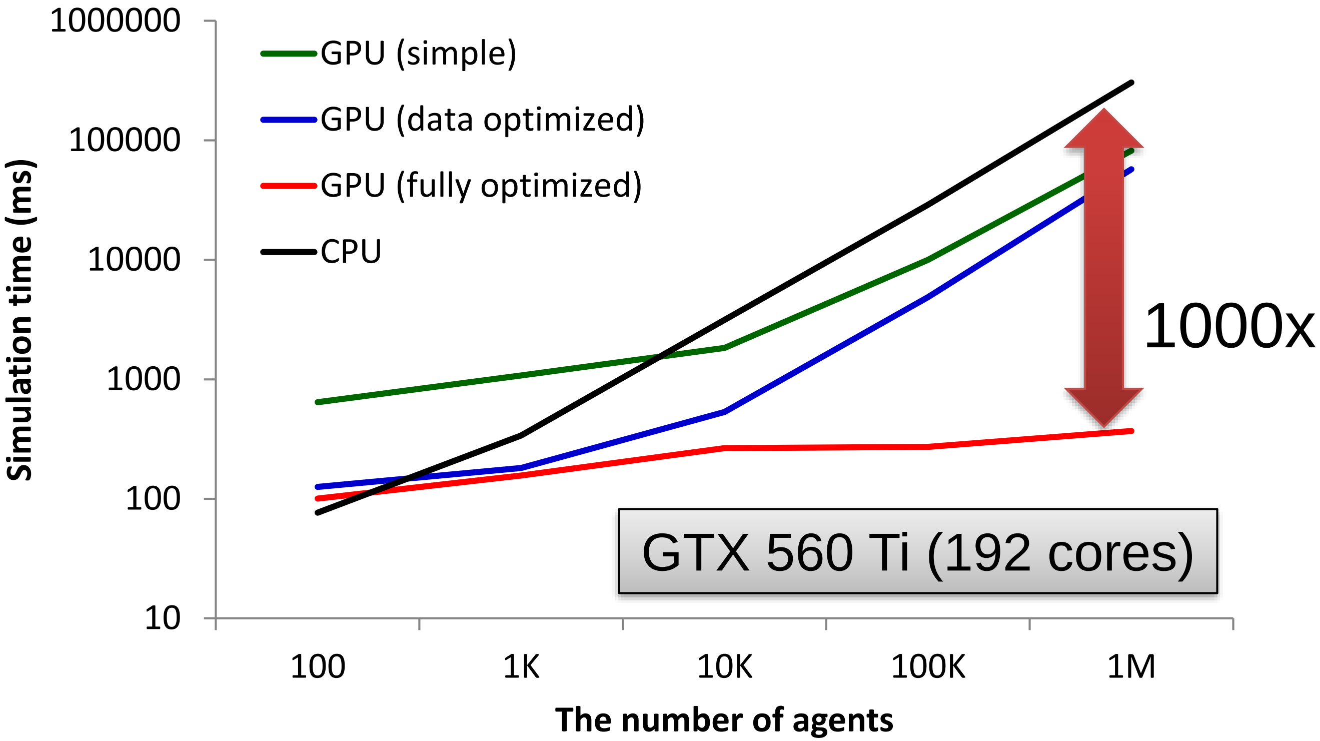


Performance per Watt

GPUs Suit Science



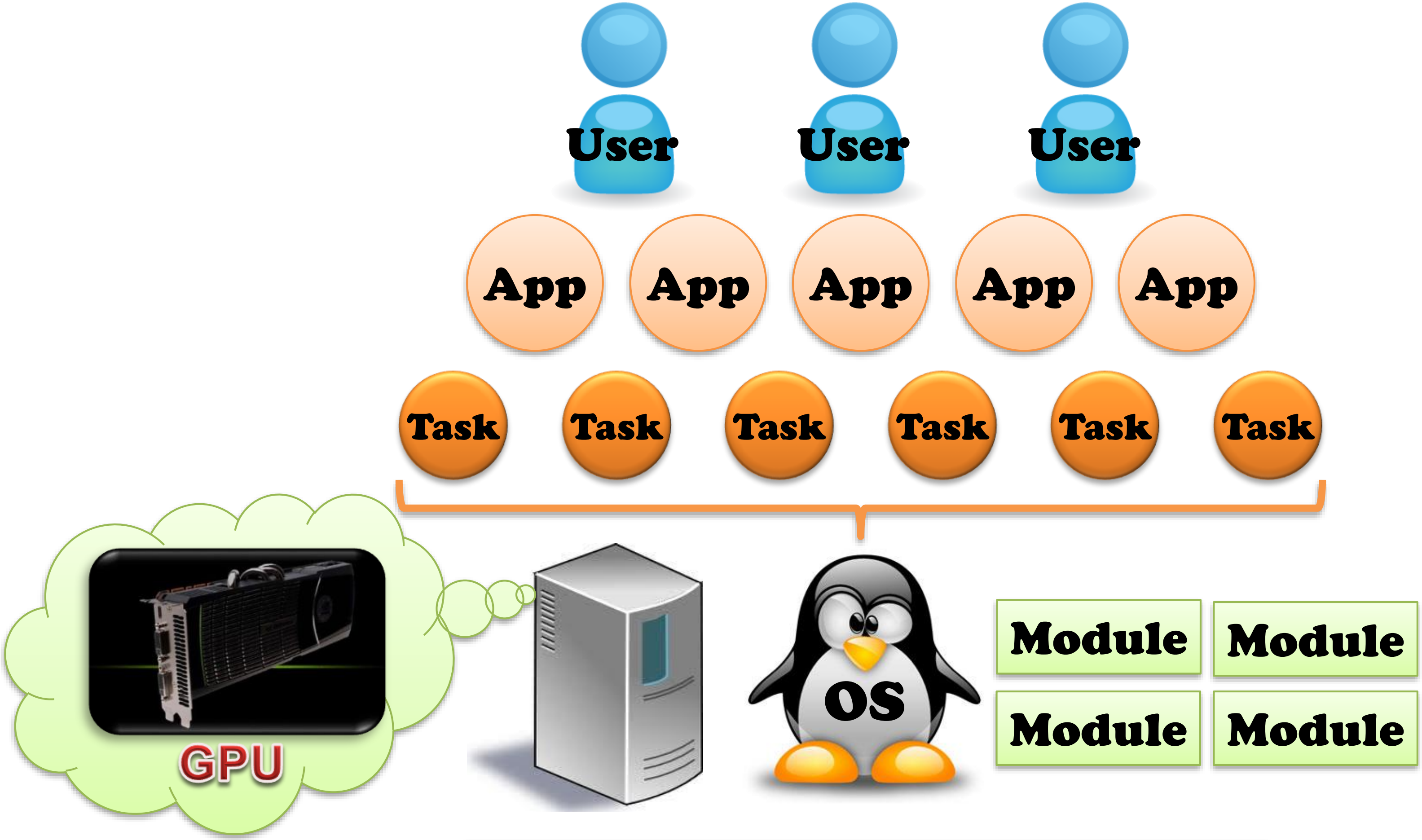
Traffic Simulation



1000x

GTX 560 Ti (192 cores)

Not Yet “General-Purpose”



User User User

App App App App App

Task Task Task Task Task Task

GPU

OS

Module Module

Module Module

GPU Resource Management

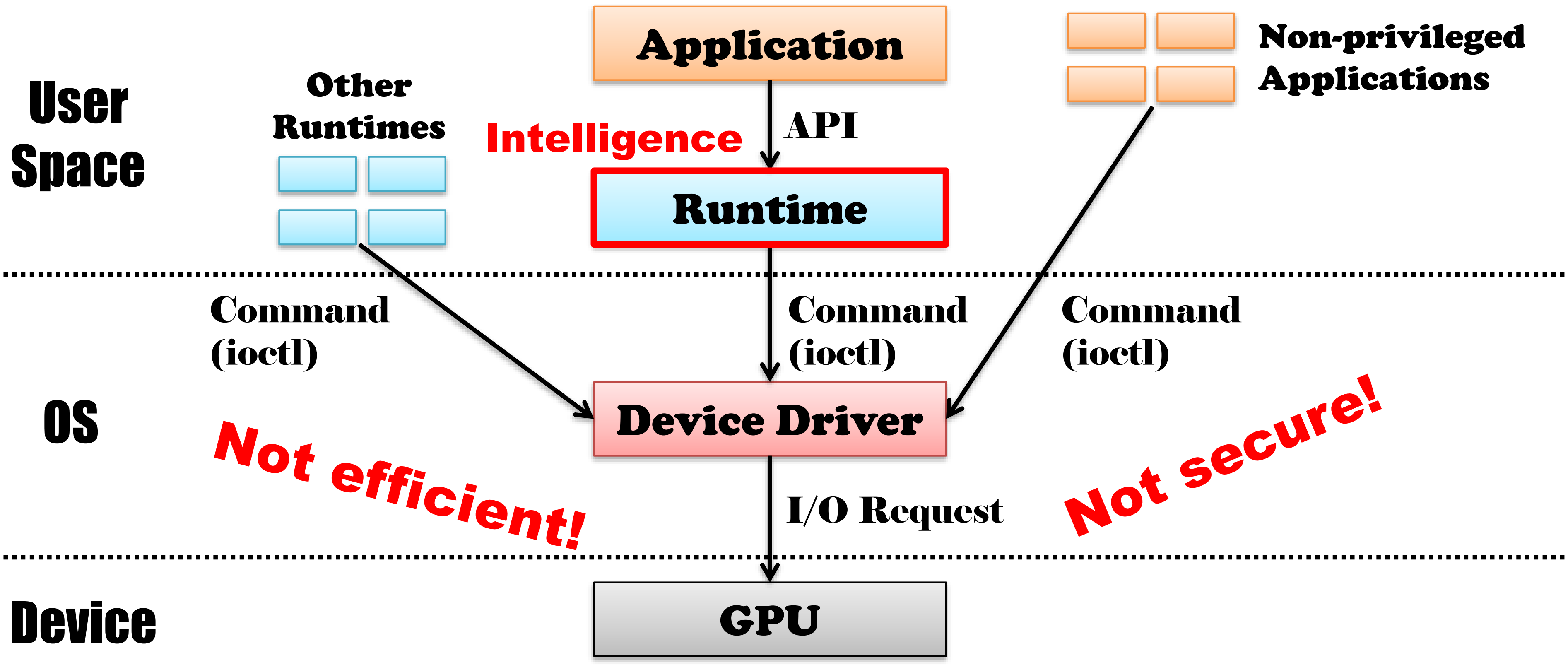
Gdev

- New approach to GPU resource management
  - – Allows the OS as well as user-space applications to use GPUs.
- New functions of GPU resource management
  - – Shared device memory (IPC)
  - – Data swapping
  - – System-level virtualization
- Open-source implementation

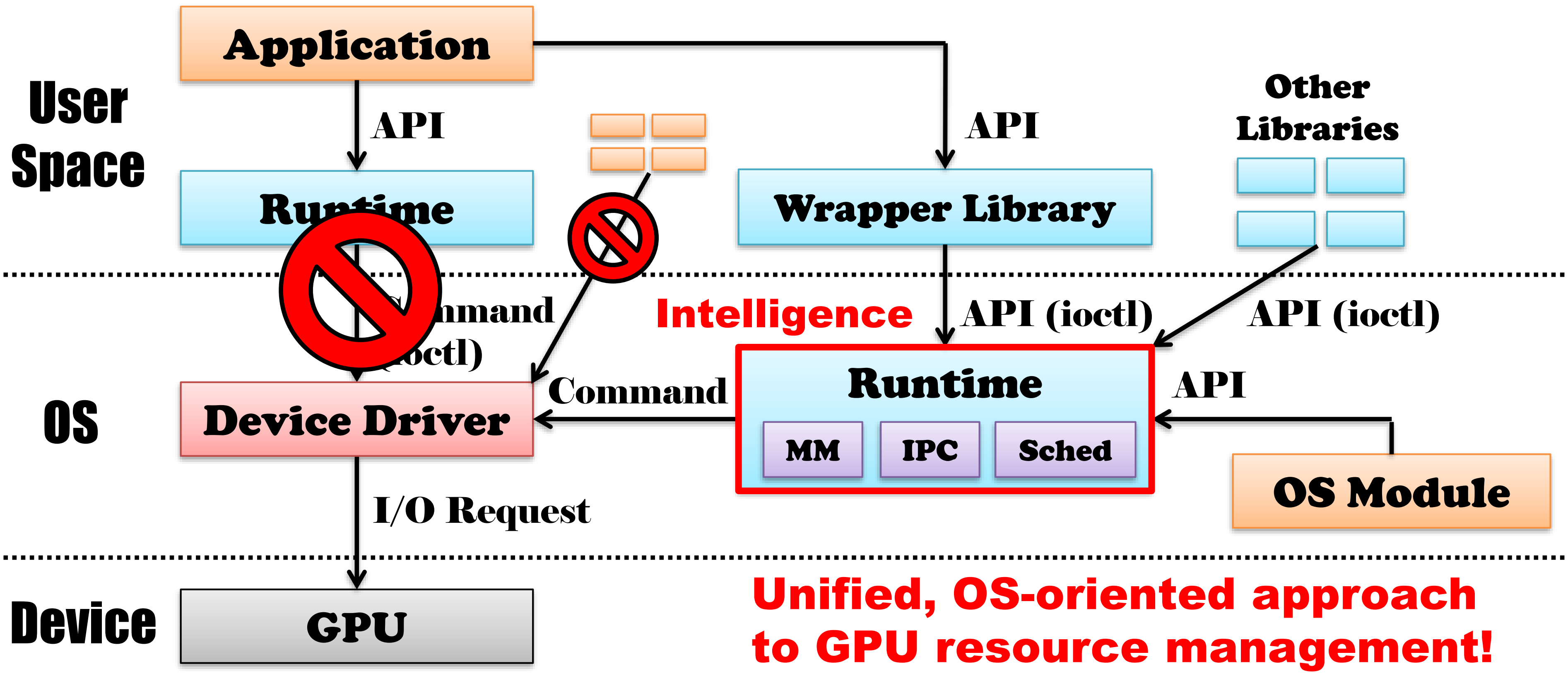
Outline

- Motivation
- Approach
- GPU Resource Management
- Evaluation
- Conclusion

Traditional Naïve Approach


User Space
OS
Device
Other Runtimes
Application
API
Intelligence
Runtime
Non-privileged Applications
Command (ioctl)
Command (ioctl)
Command (ioctl)
Device Driver
I/O Request
GPU
Not efficient!
Not secure!

Gdev Approach


User Space
OS
Device
Application
API
Runtime
mmand
ioctl)
Device Driver
I/O Request
GPU
Command
API
Wrapper Library
Other Libraries
Intelligence
API (ioctl)
API (ioctl)
Runtime
MM
IPC
Sched
API
OS Module

Unified, OS-oriented approach to GPU resource management!

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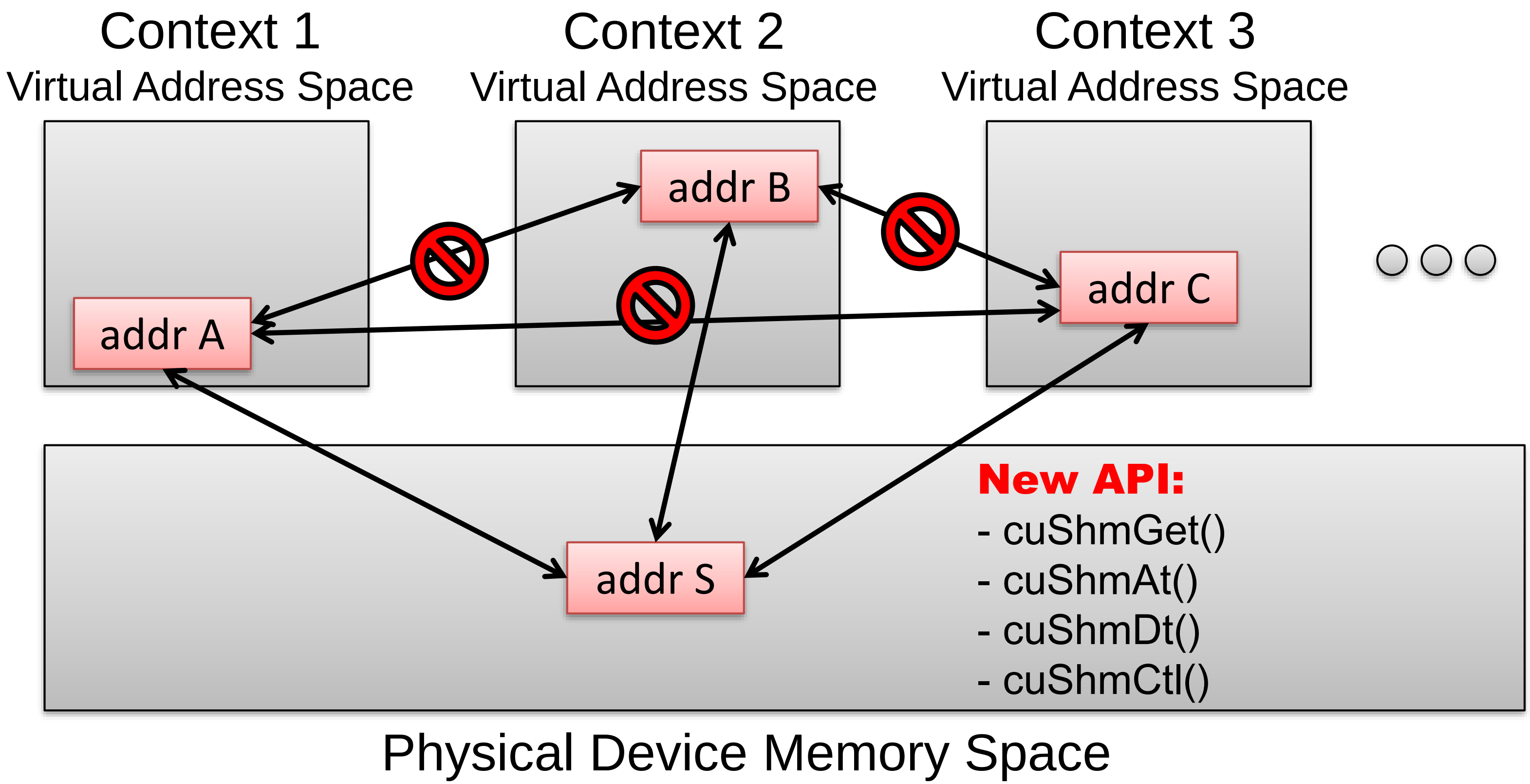
Shared Device Memory



Context 1
Virtual Address Space

Context 2
Virtual Address Space

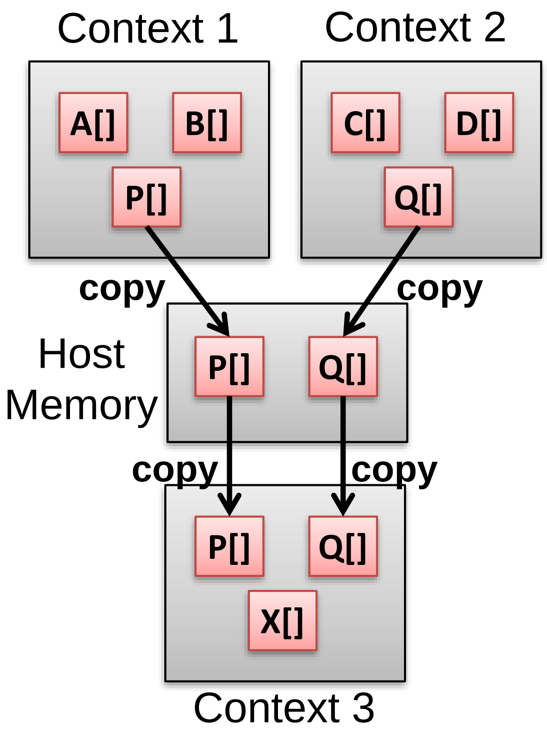
Context 3
Virtual Address Space

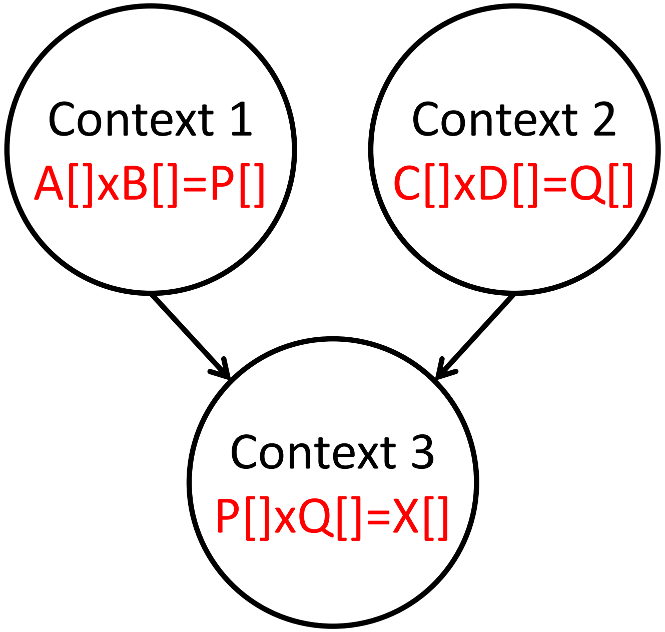
New API:
- cuShmGet()
- cuShmAt()
- cuShmDt()
- cuShmCtl()

Physical Device Memory Space

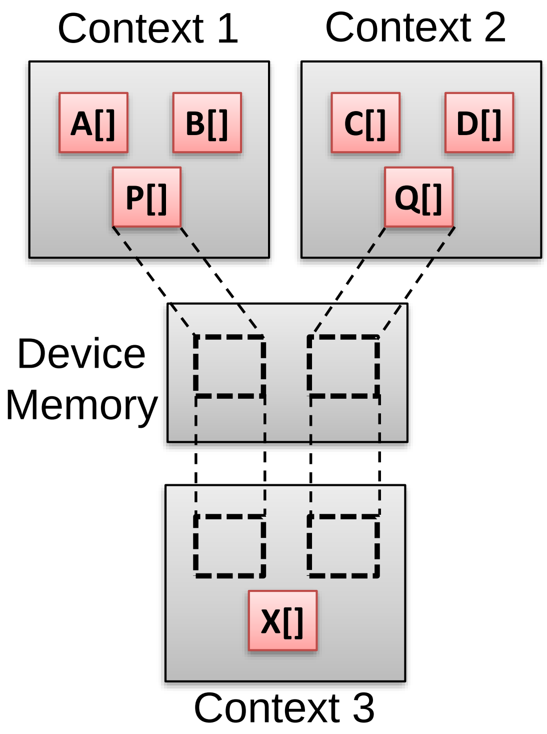
E.g., Dataflow (2x2 Tree)

No Shared Memory

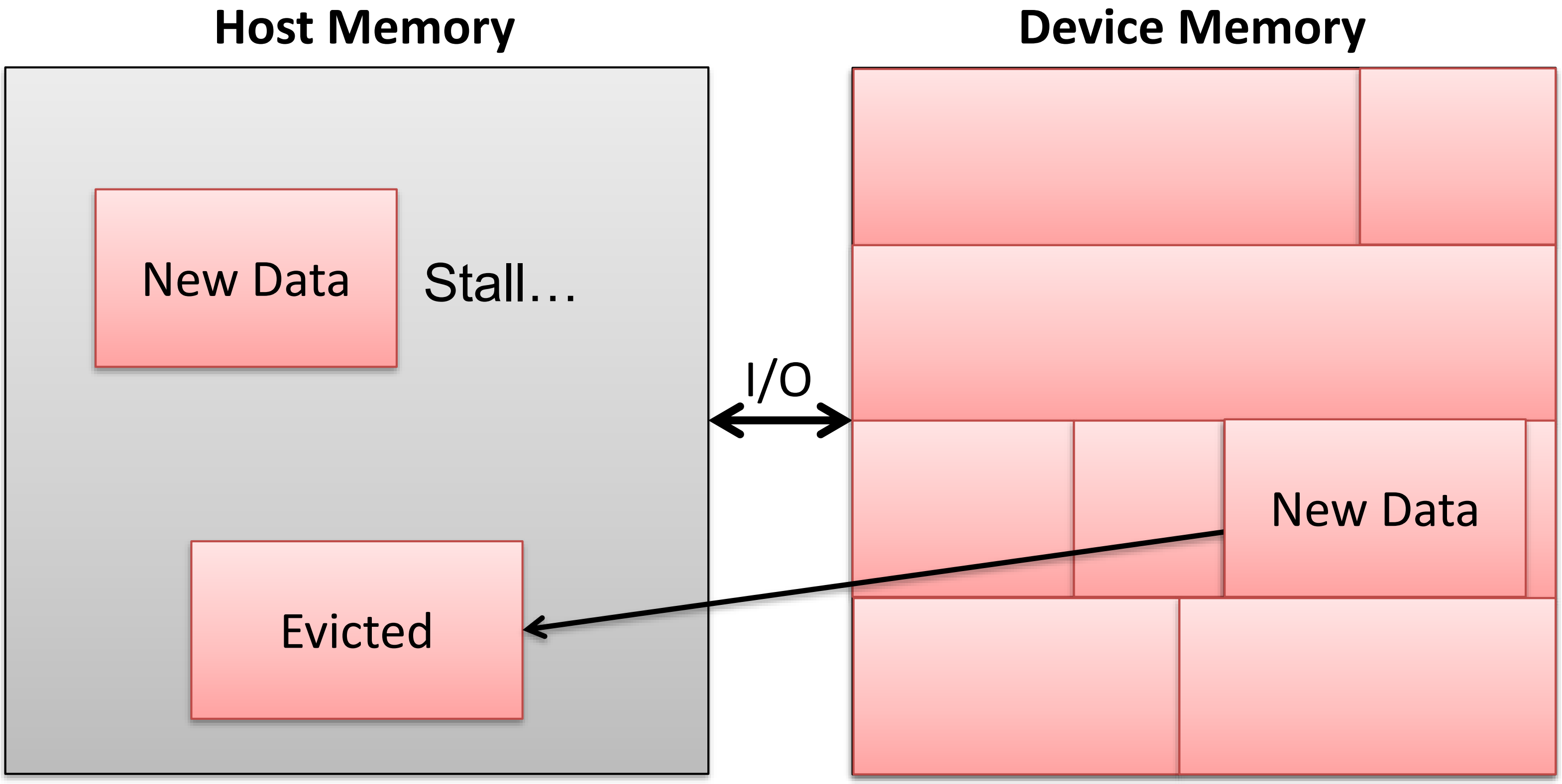

Context 1
Context 2
A[]
B[]
P[]
C[]
D[]
Q[]
copy
copy
Host
Memory
P[]
Q[]
copy
copy
P[]
Q[]
X[]
Context 3


Context 1
A[]xB[]=P[]
Context 2
C[]xD[]=Q[]
Context 3
P[]xQ[]=X[]

Shared Memory IPC


Context 1
Context 2
A[]
B[]
P[]
C[]
D[]
Q[]
Device
Memory
X[]
Context 3

Data Swapping


Host Memory

Device Memory

New Data

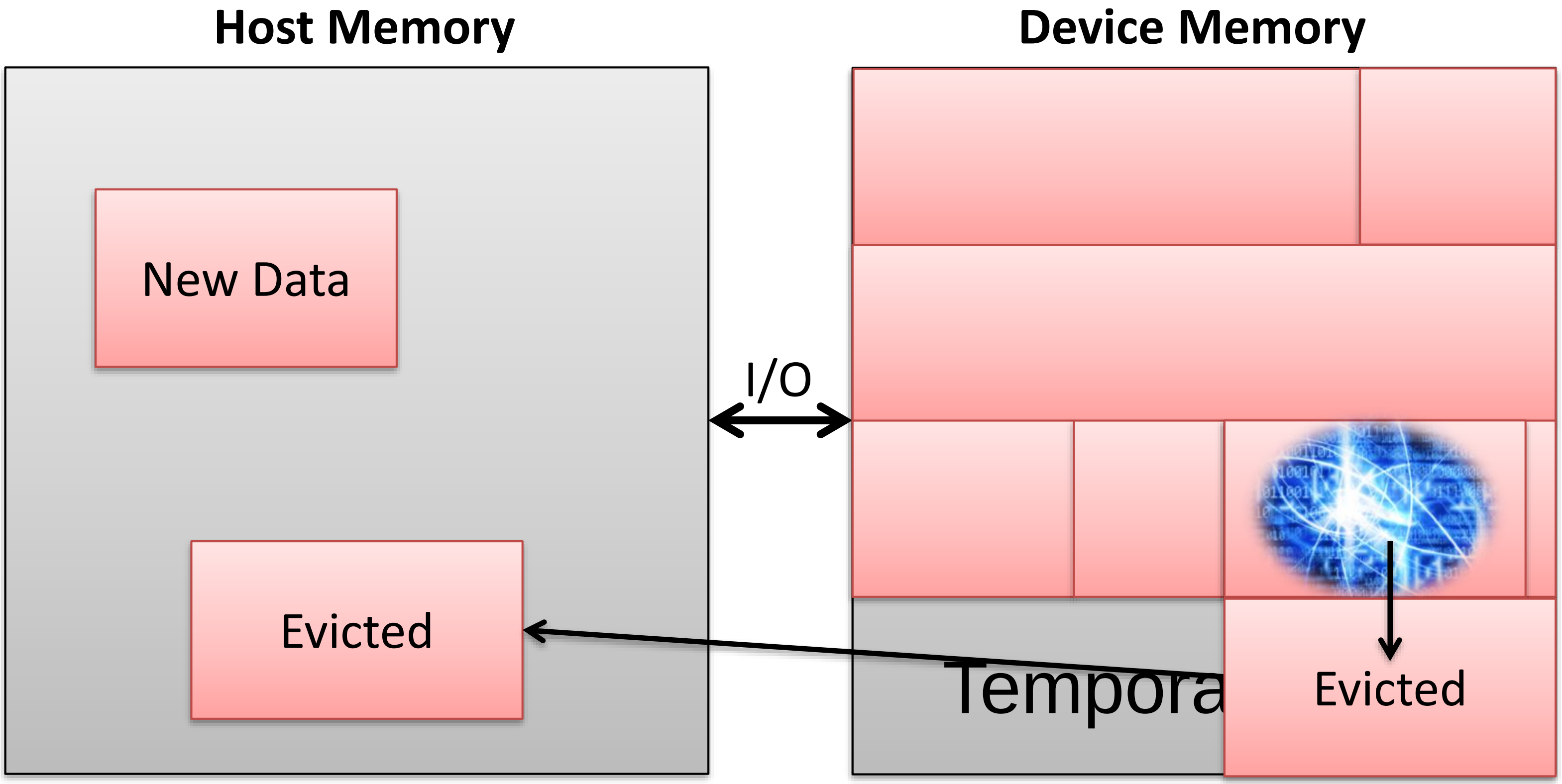
Stall…

I/O

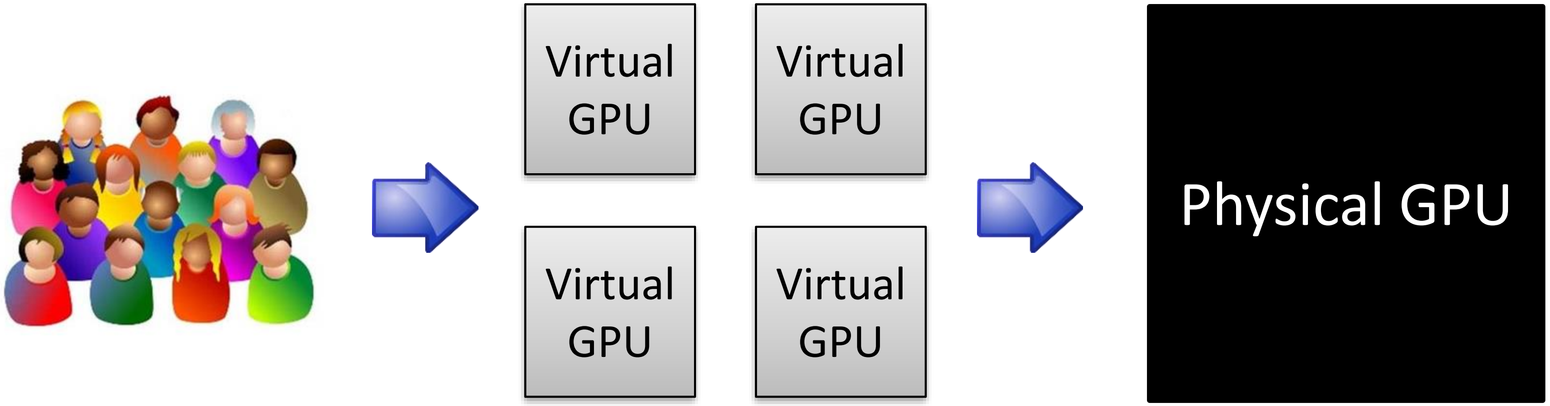
New Data

Evicted

Data Swapping (Enhanced)


Host Memory
Device Memory
New Data
Evicted
I/O
Tempora
Evicted

GPU Virtualization



Virtual GPU

Virtual GPU

Virtual GPU

Virtual GPU

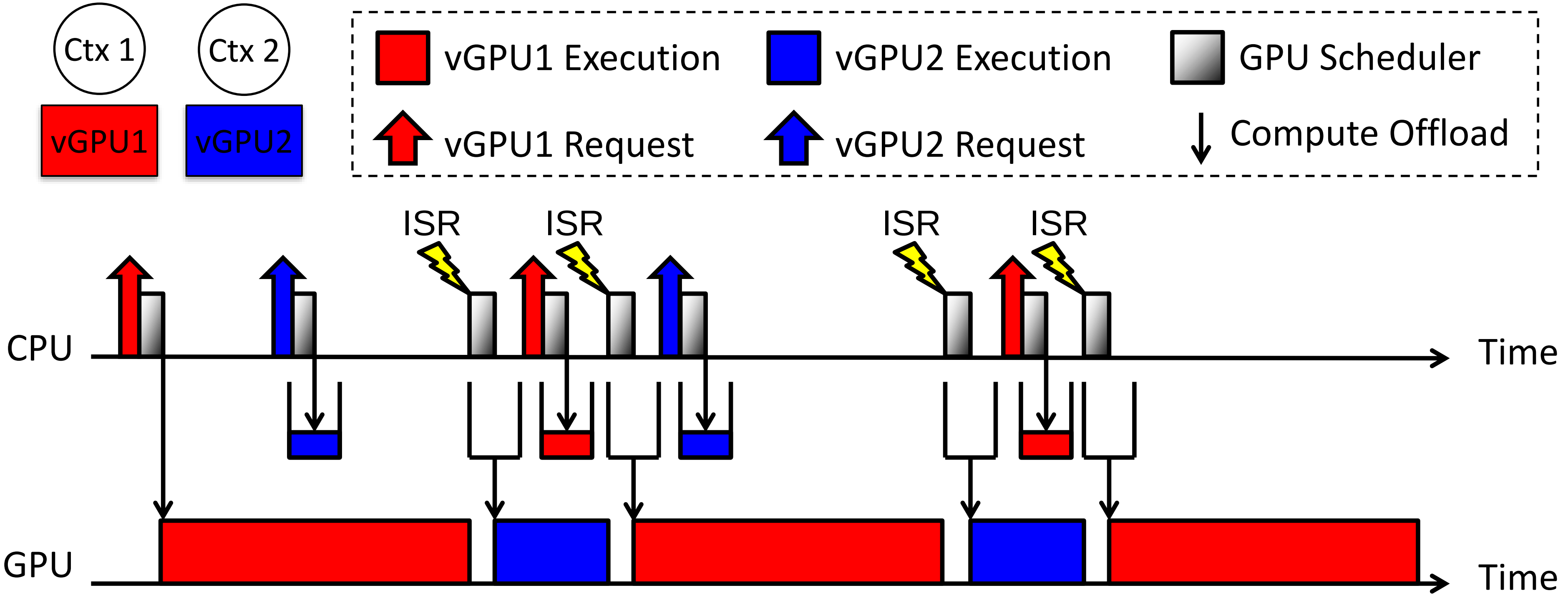
Physical GPU

`/dev/gdev0`
`/dev/gdev1`
`/dev/gdev2`
`/dev/gdev3`
…

`/dev/dri/card0`
(real device file)

Existing GPU Schedulers

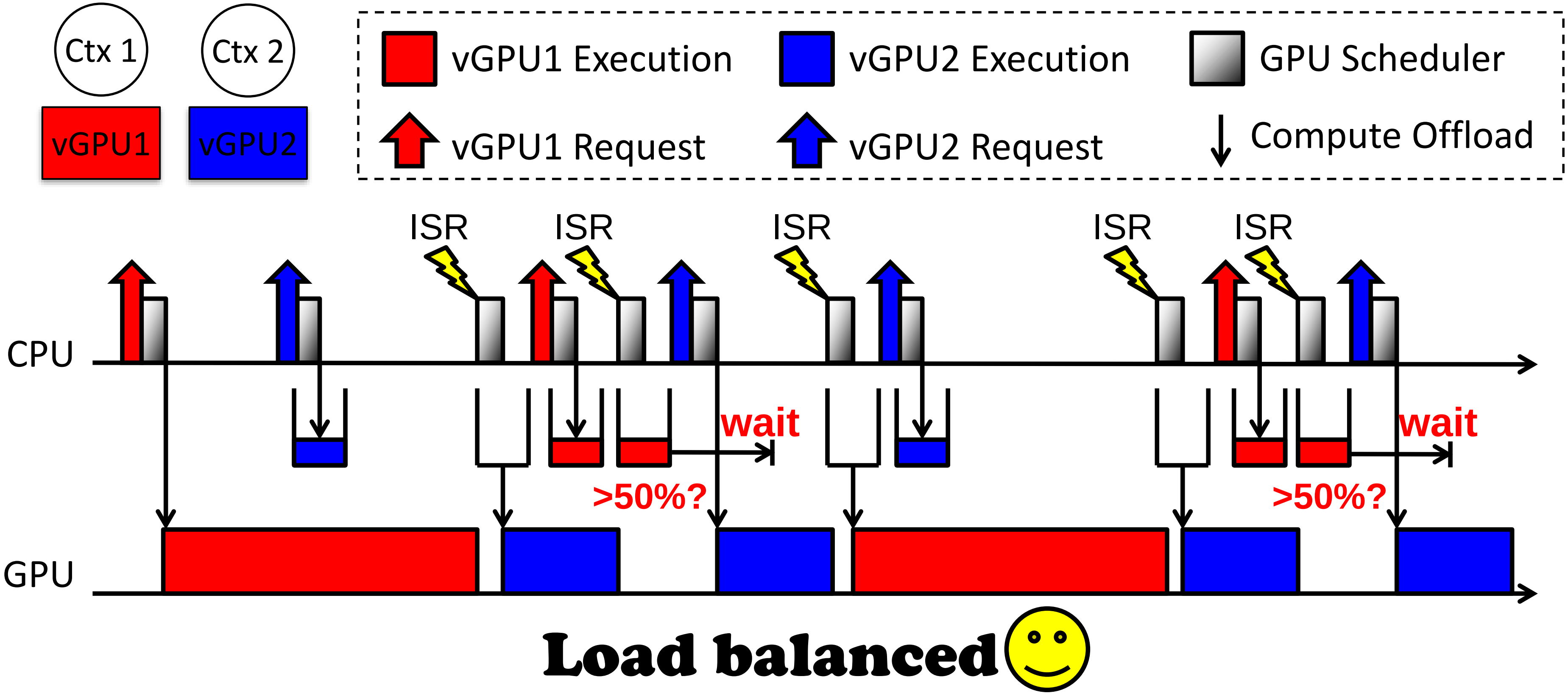
Queue and dispatch [Kato ATC11] [Kato RTSS11]


Ctx 1
Ctx 2
vGPU1
vGPU2
ISR
ISR
ISR
ISR
CPU
Time
GPU
Time

🟥 vGPU1 Execution
🟦 vGPU2 Execution
▨ GPU Scheduler
⇧ vGPU1 Request
⇧ vGPU2 Request
↓ Compute Offload

Load unbalanced!

Bandwidth-aware non-preemptive device (BAND) Scheduler


Ctx 1
Ctx 2
vGPU1
vGPU2
vGPU1 Execution
vGPU2 Execution
GPU Scheduler
vGPU1 Request
vGPU2 Request
Compute Offload
ISR
ISR
ISR
ISR
ISR
CPU
wait
wait
>50%?
>50%?
GPU

Load balanced ☺

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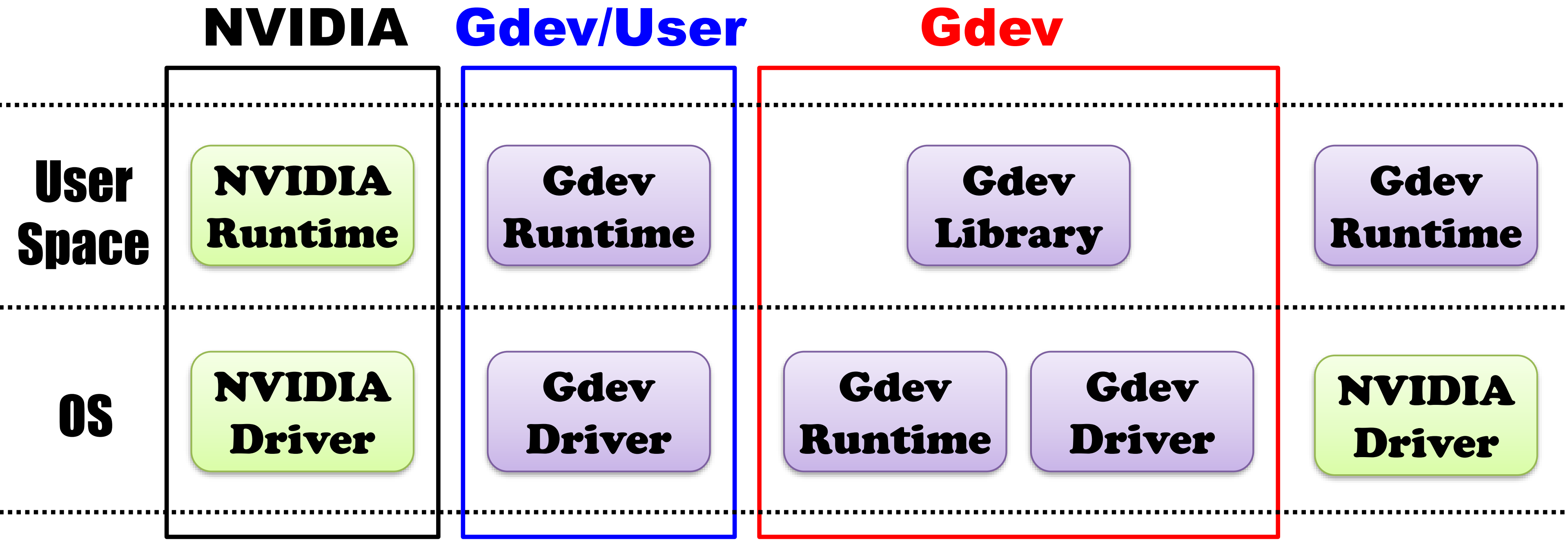
Experimental Setup

- Linux kernel 2.6.39
- NVIDIA GeForce GTX 480
- Intel Core 2 Extreme QX9650
- NVIDIA CUDA Compiler 4.0 and GCC 4.4.6
- Benchmarks & Applications:
  - Rodinia benchmark [Che *et al*, IISWC’09]
  - eCryptfs encrypted filesystem
  - FAST database search [Kim *et al*, SIGMOD’10]
  - PTask dataflow benchmarks [Rossbach *et al*, SOSP’11]

Runtime and Driver Choice



NVIDIA

Gdev/User

Gdev

User Space

OS

NVIDIA Runtime

NVIDIA Driver

Gdev Runtime

Gdev Driver

Gdev Library

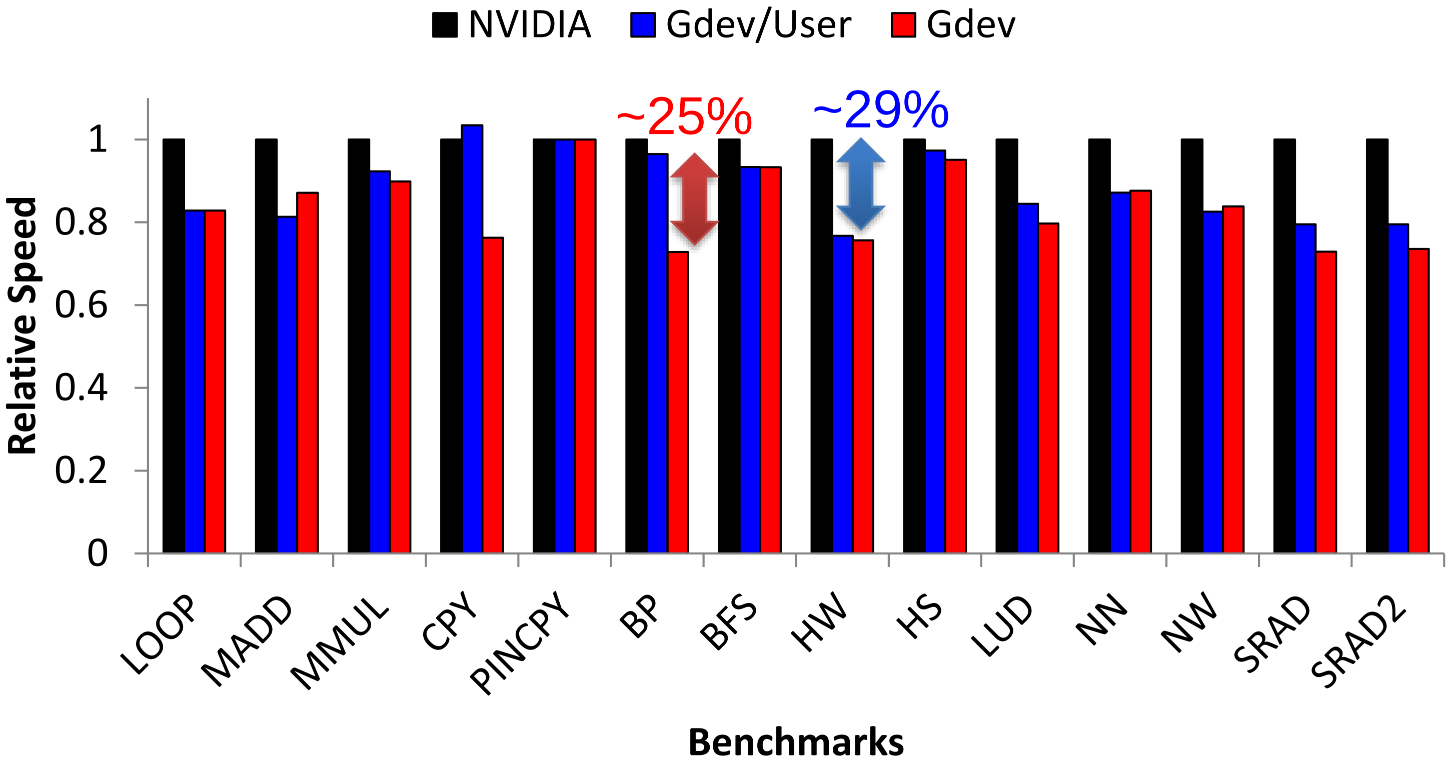
Gdev Runtime

Gdev Driver

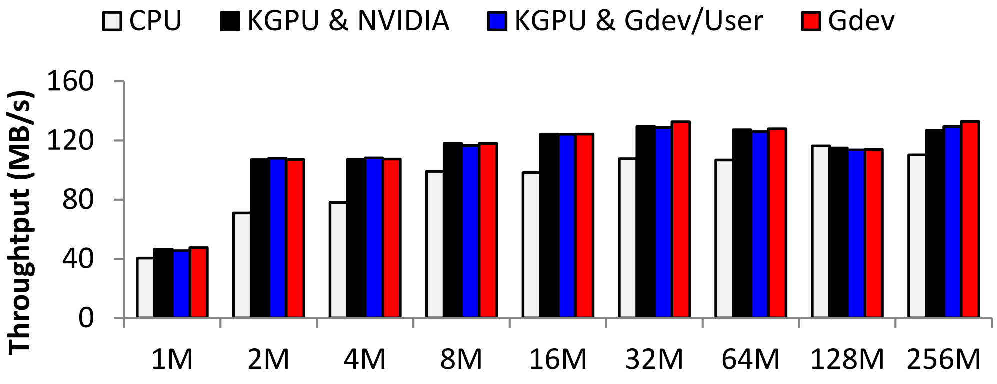
Gdev Runtime

NVIDIA Driver

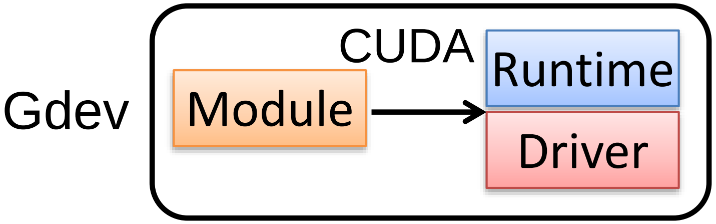
Basic Performance



eCryptfs Read&Write Throughput



Read throughput


Gdev

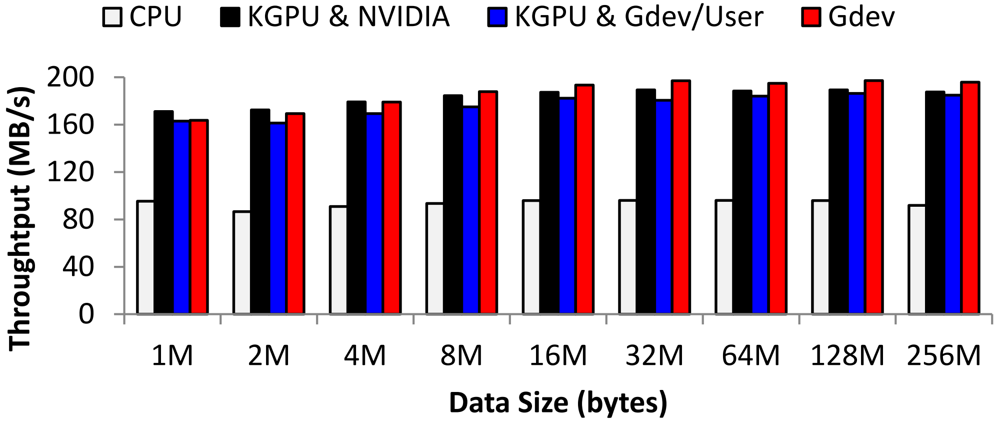
Module

CUDA

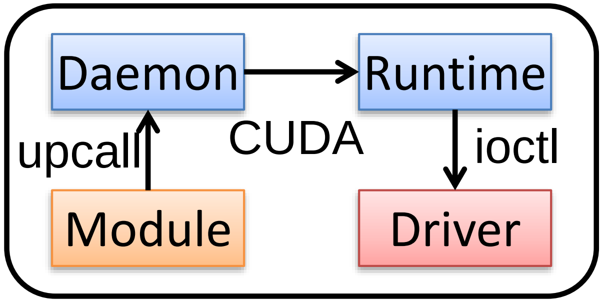
Runtime

Driver

Write throughput



KGPU
Sun *et. al.*
2012


Daemon

Runtime

upcall

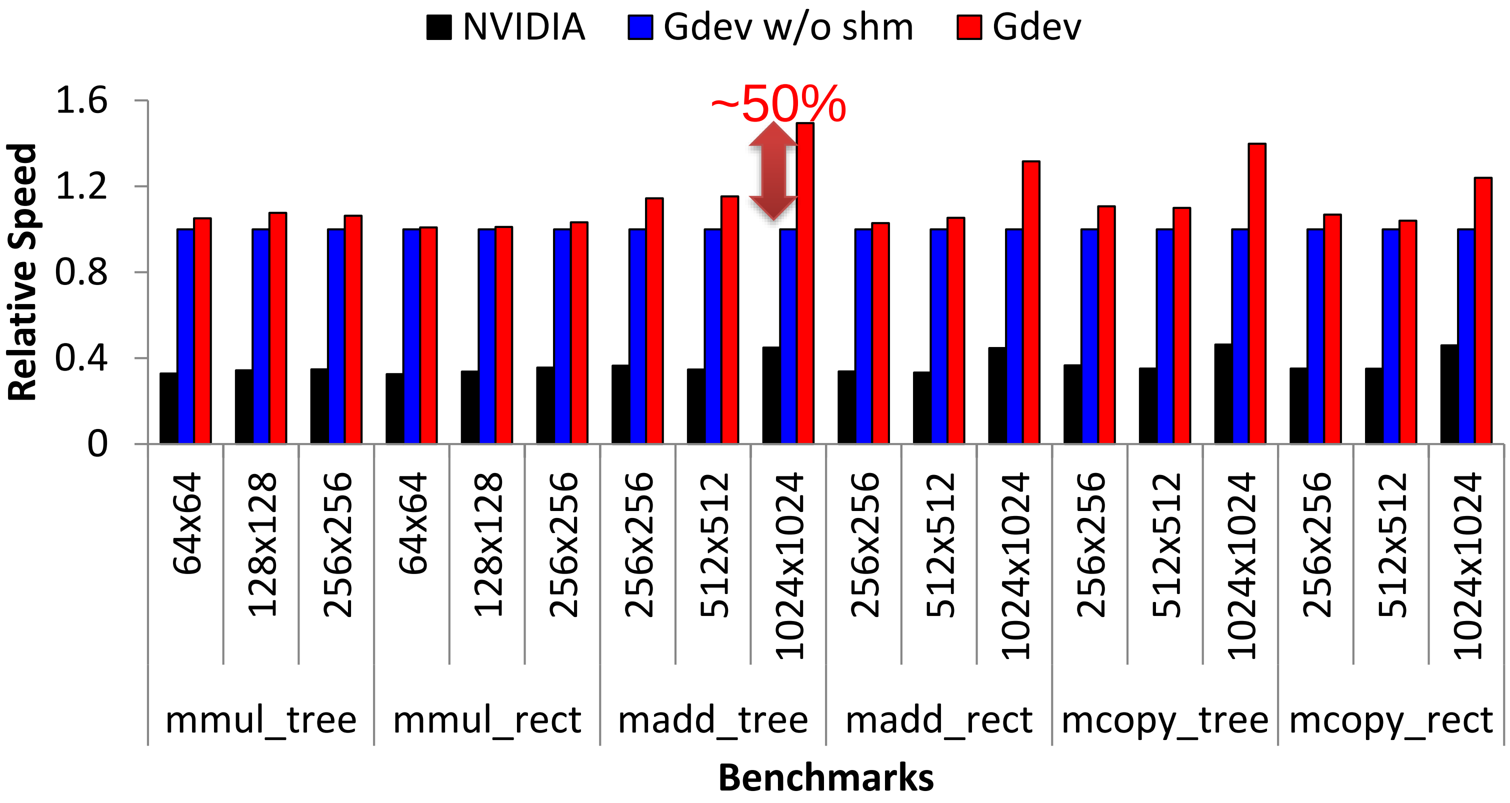
CUDA

ioctl

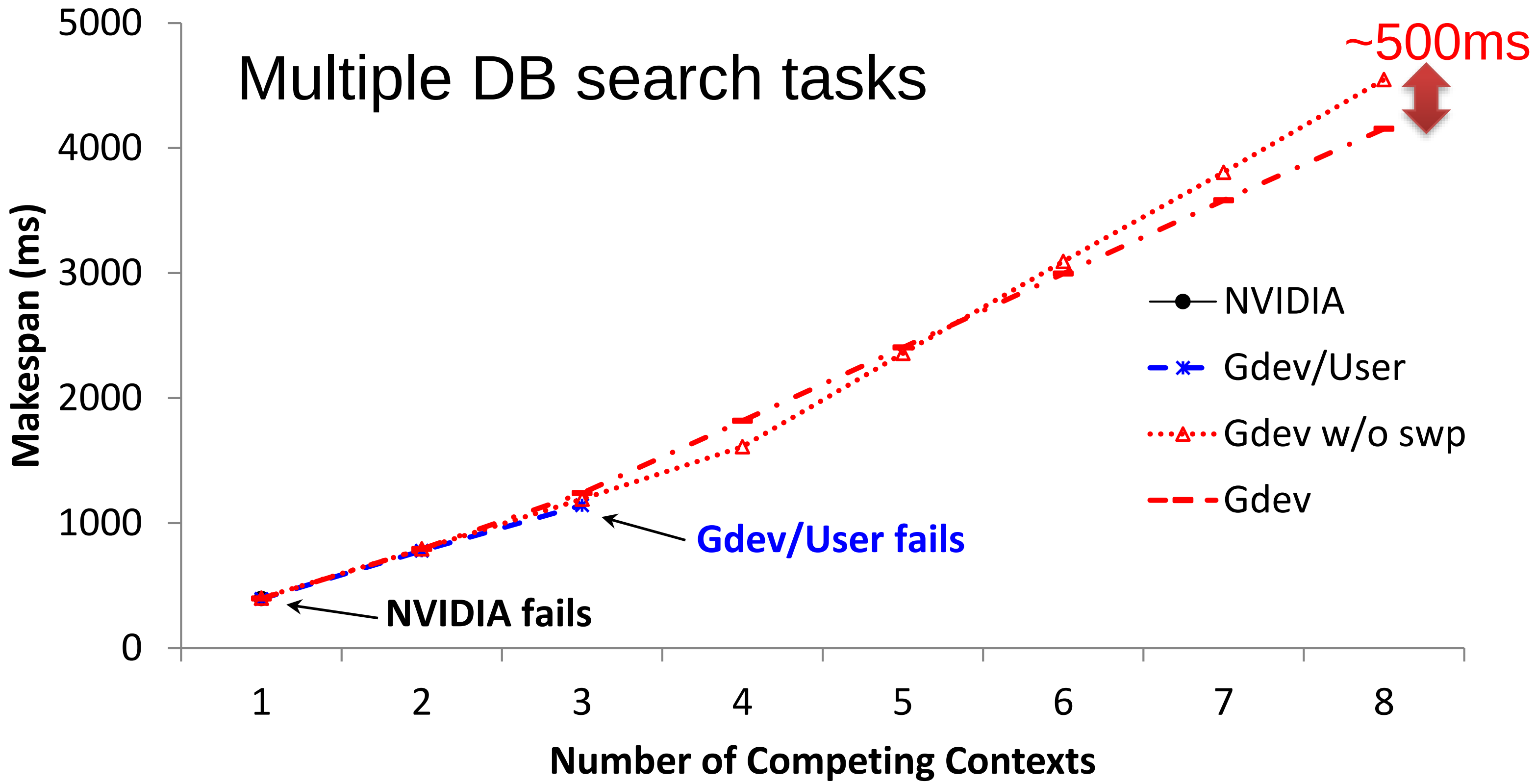
Module

Driver

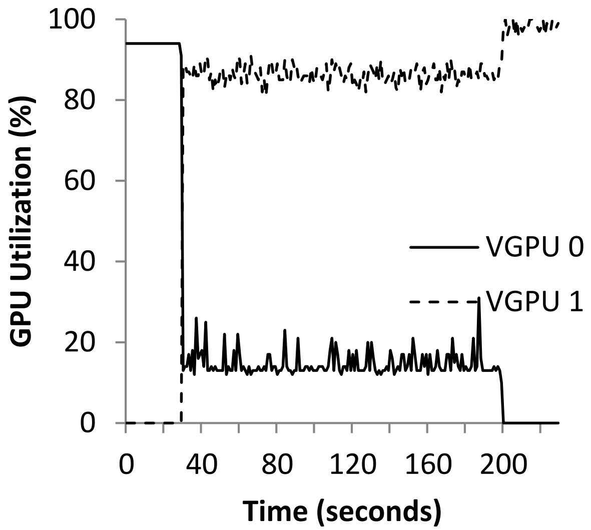
Impact of Shared Device Memory



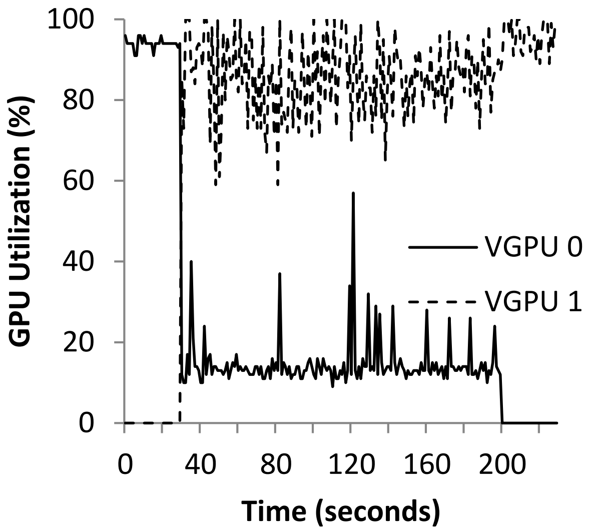
Impact of Data Swapping



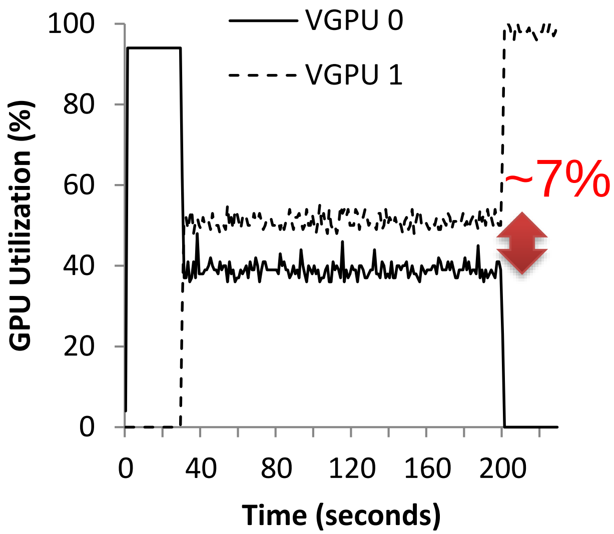
Virtual GPU Isolation



No scheduling
(FIFO)



Xen VM Policy
(Credit)



Gdev Policy
(BAND)

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- Motivation
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- **Conclusion**

Concluding Remarks

- Gdev is an OS approach to **first-class** GPU resource management.
  - GPUs can be used by the OS.
  - GPUs can be protected by the OS.
  - GPUs can be multi-tasked by the OS.
  - Compromising basic performance to some extent.

Concluding Remarks

Gdev is **open-source**.

Facilitate systems research.

Visit http://sys.ertl.jp/gdev/.

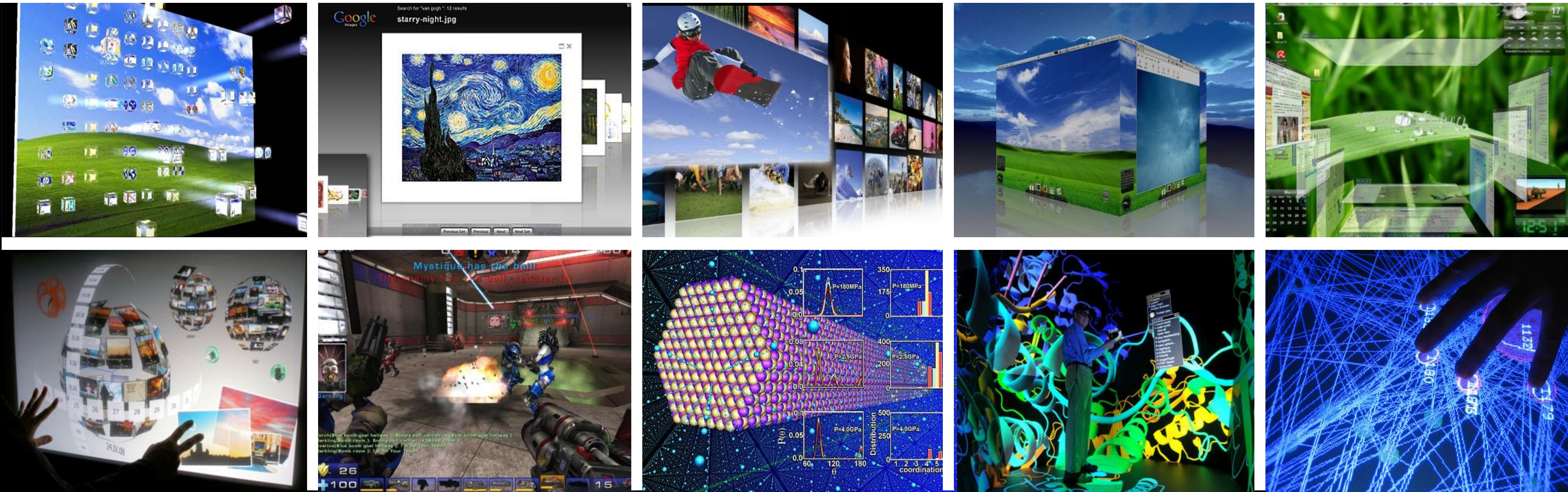
What's up-to-date:

- RAID6 erasure coding acceleration.
- Dynamic power management.
- Zero-copy between I/O devices and GPUs.

NVIDIA
GEFORCE GTX 280
EVGA
GEFORCE 9500 GT
NVIDIA
GEFORCE GTX 470M

Thank You!

Questions?


Google
starry-night.jpg
Mystique has the ball!
P=180MPa
P=2.5GPa
P=4.0GPa
coordination