Measuring Per-Frame Energy Consumption of Real-Time Graphics Applications

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Why care about energy?

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Computing devices increasingly battery powered

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- Mobile phones
- Laptops
- Tablets
- Wearable technology

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Smaller form factors require graphics

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Computing devices increasingly battery powered

- Mobile phones
- Laptops
- Tablets
- Wearable technology

Smaller form factors require graphics

- Heat dissipation
- Battery size and time

Why **measure** the energy?

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Why not simulate?

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Why not simulate?

- Simulation models need to be trained

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- Hardware specific

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Why not simulate?

- Simulation models need to be trained
- Hardware specific
- Requires additional data: rendering time, primitive count…

Why **measure** the energy?

Why not simulate?

- Simulation models need to be trained
- Hardware specific
- Requires additional data: rendering time, primitive count…
- Need to validate

Why measure **per-frame** energy?

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Correlation

Why measure **per-frame** energy?

Correlation

- Visually inspect energy-hungry frames

Why measure **per-frame** energy?

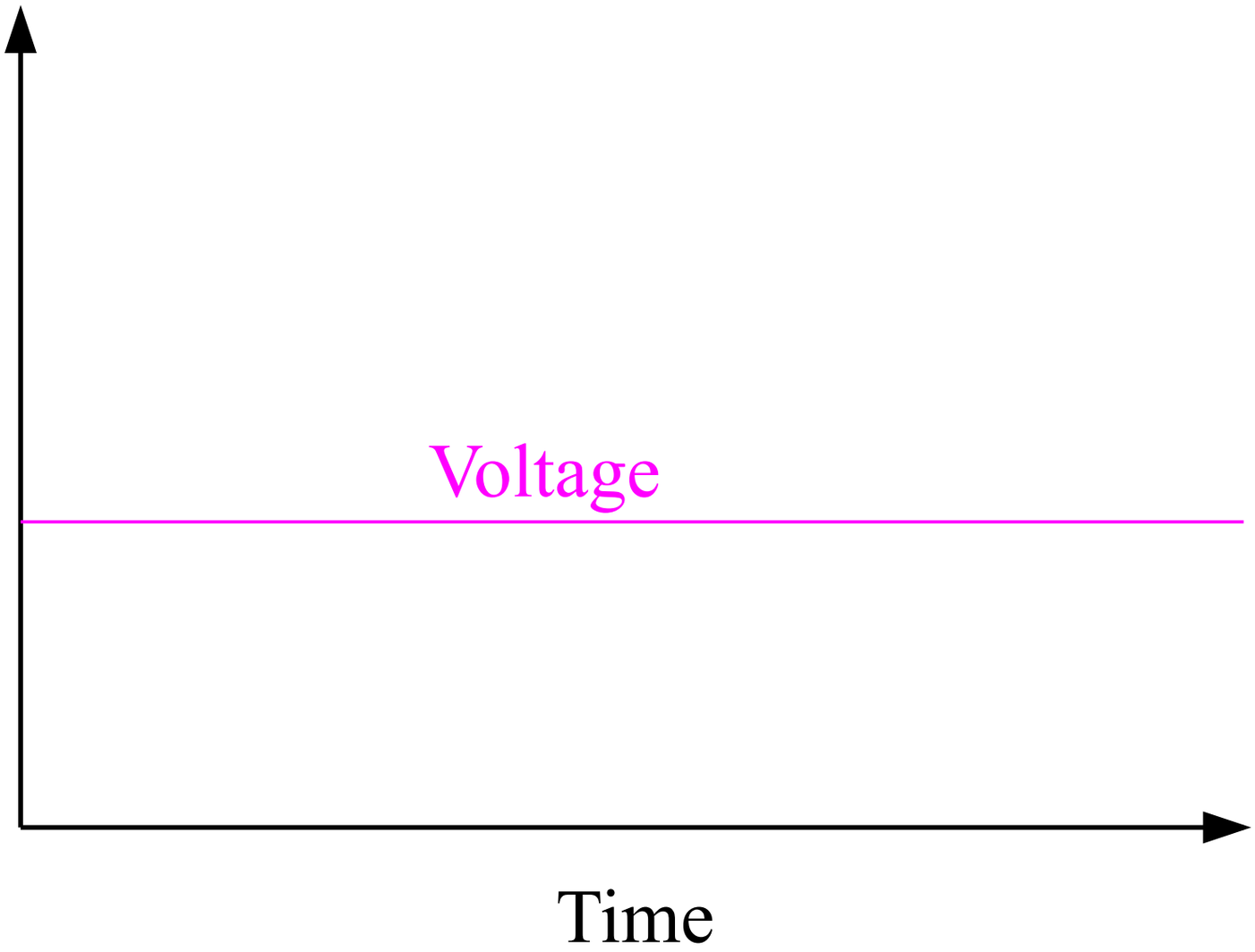
Correlation

- Visually inspect energy-hungry frames
- Other data collected per frame
  - Rendering time
  - Primitive count

Energy

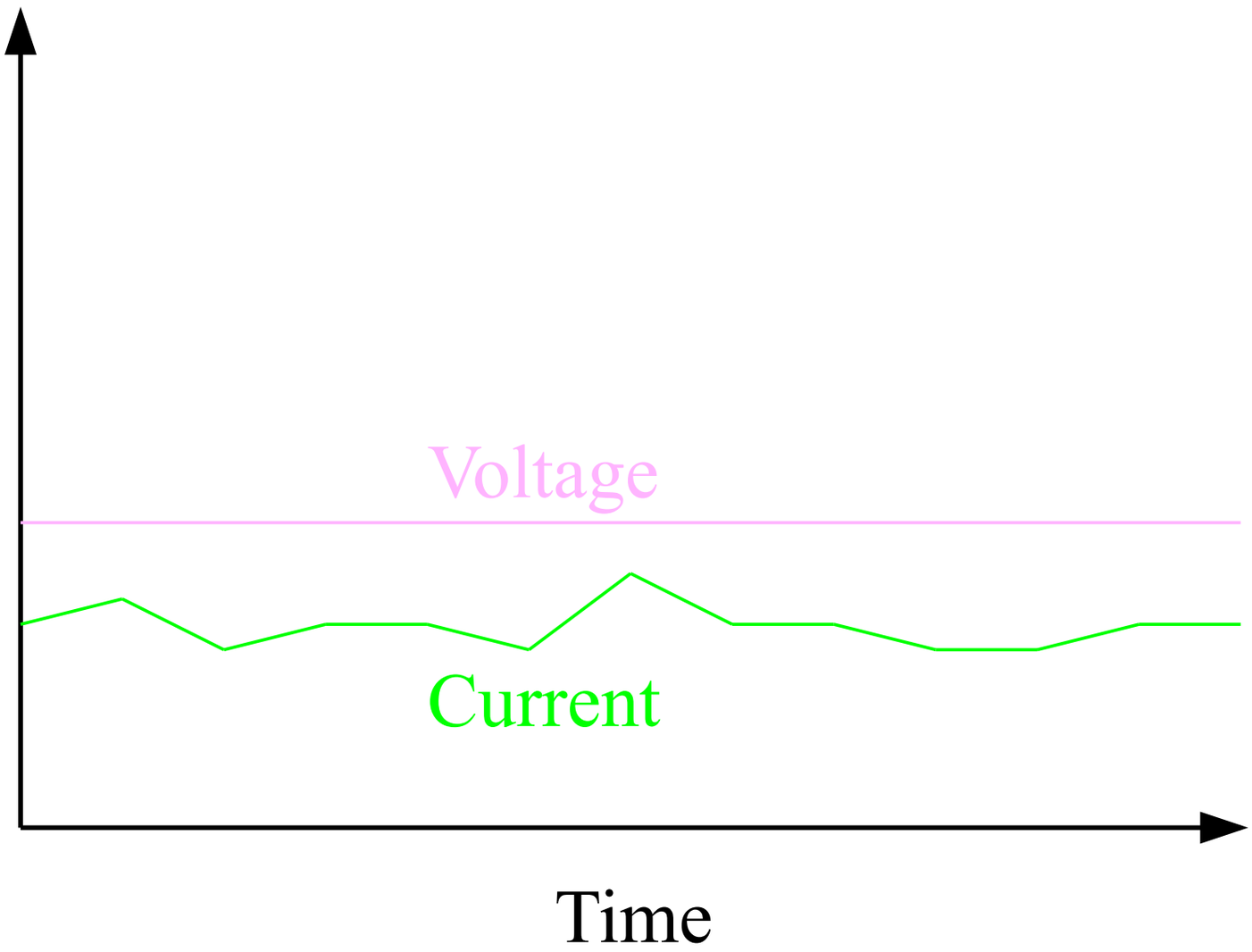
Energy

Voltage U (volt)



Energy

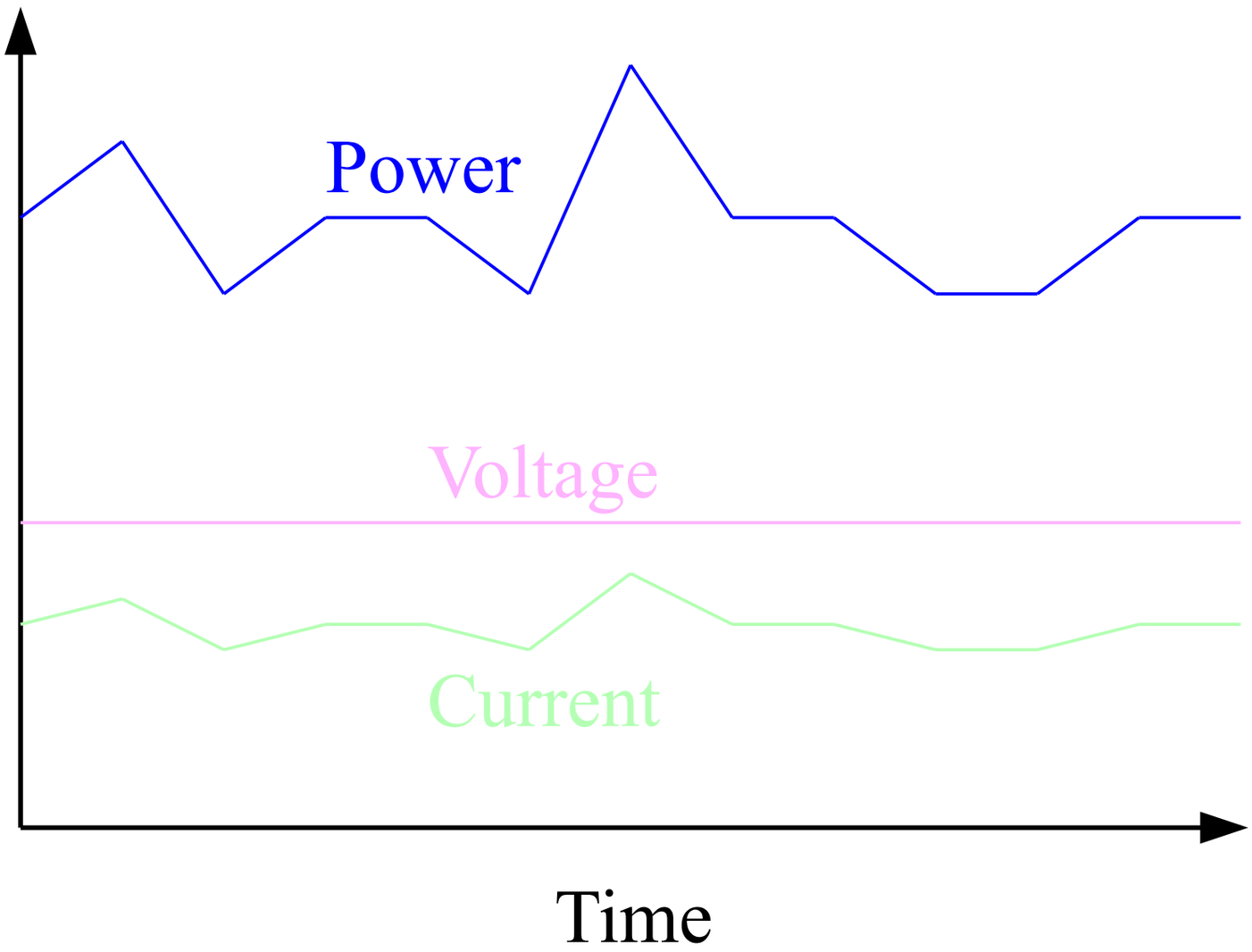
Current I (ampere)



Energy

Power P (watt)

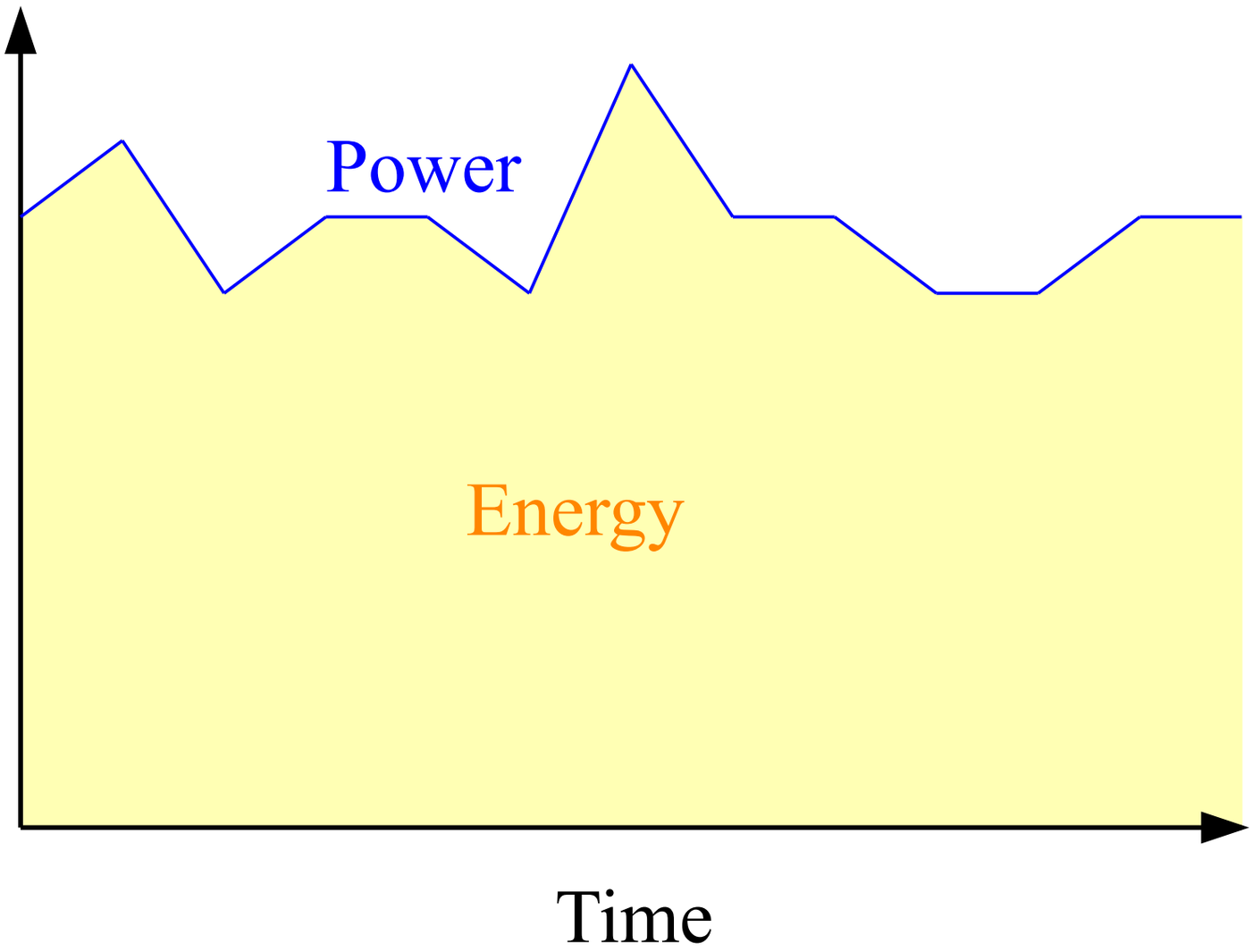
P = U*I



Energy

Energy E (joules)

$$E = \int P(t)\, dt$$



Our method

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Goal: Per-frame energy

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Method overview

Three main steps

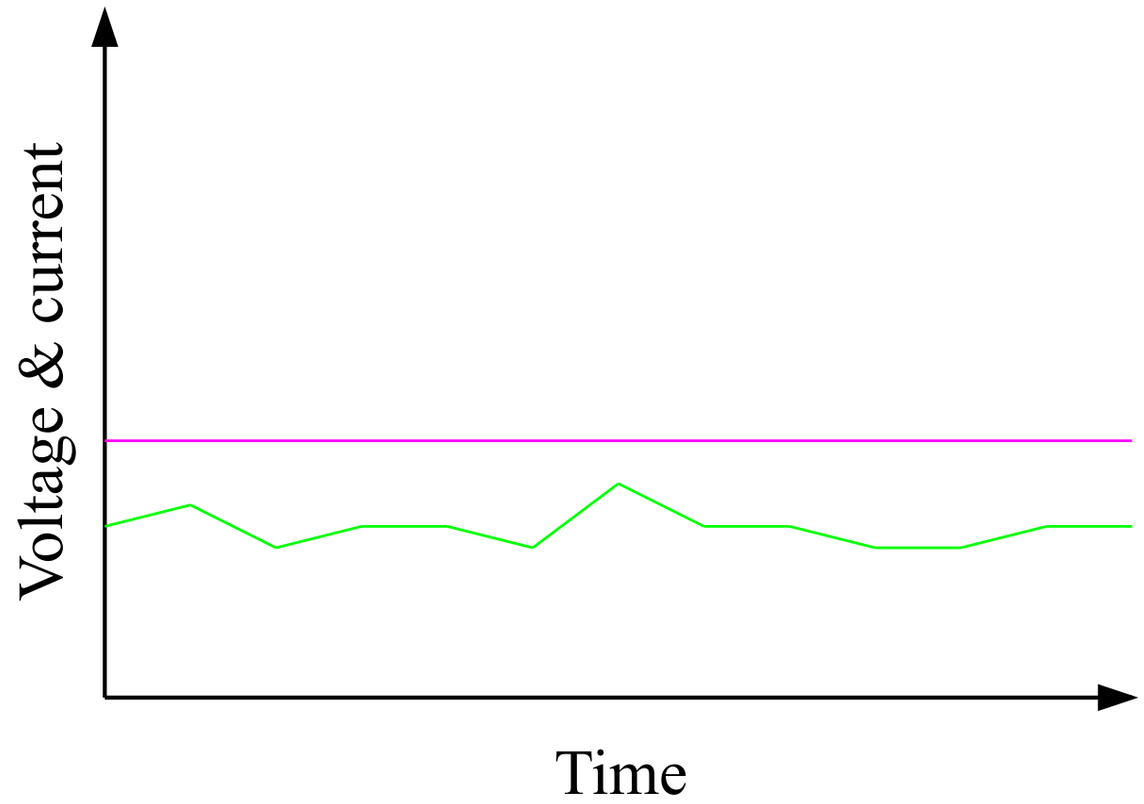
Our method

Goal: Per-frame energy

Method overview

Three main steps

- Record current and voltage



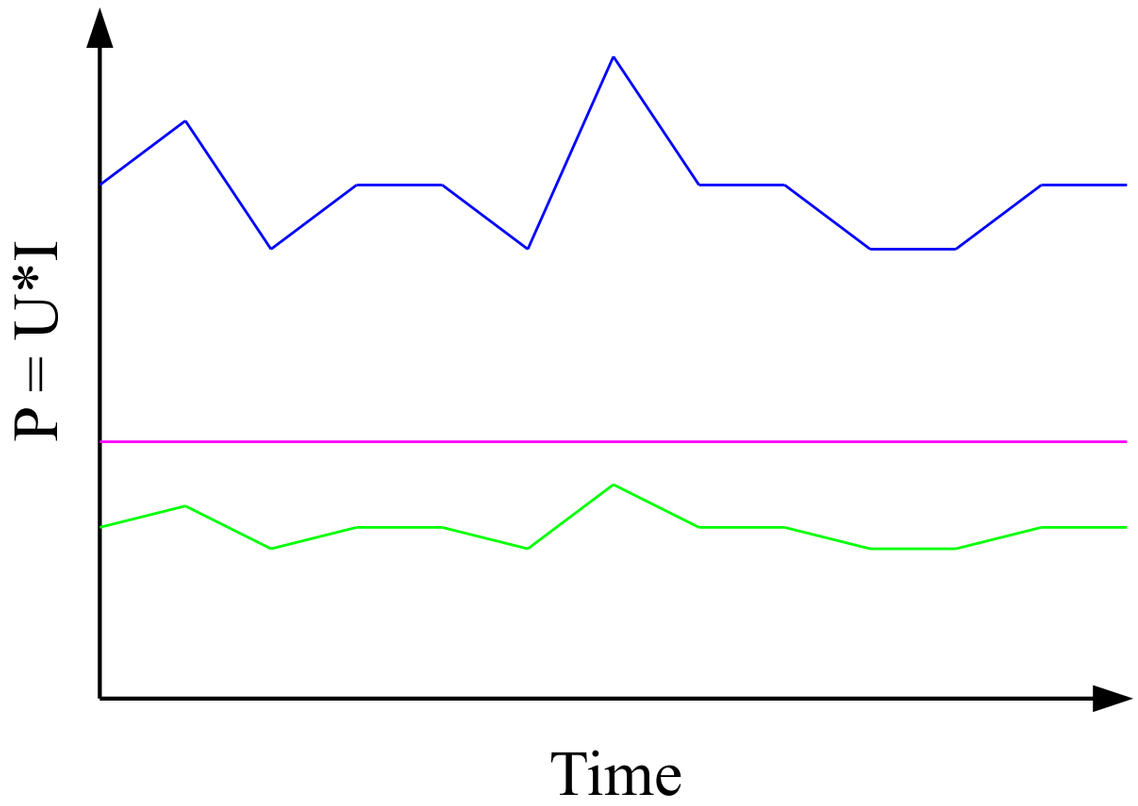
Our method

Goal: Per-frame energy

Method overview

Three main steps

- Record current and voltage
  - To get power



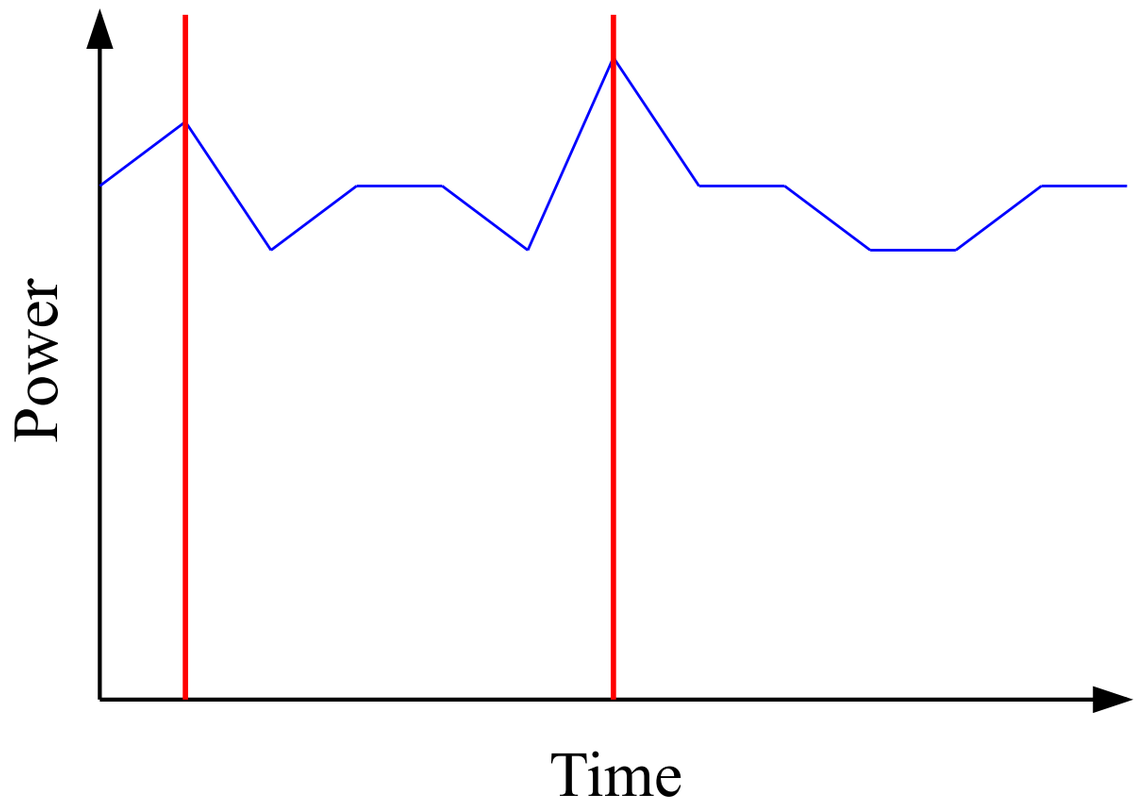
Our method

Goal: Per-frame energy

Method overview

Three main steps

- Record current and voltage
  - To get power
- Acquire timestamps



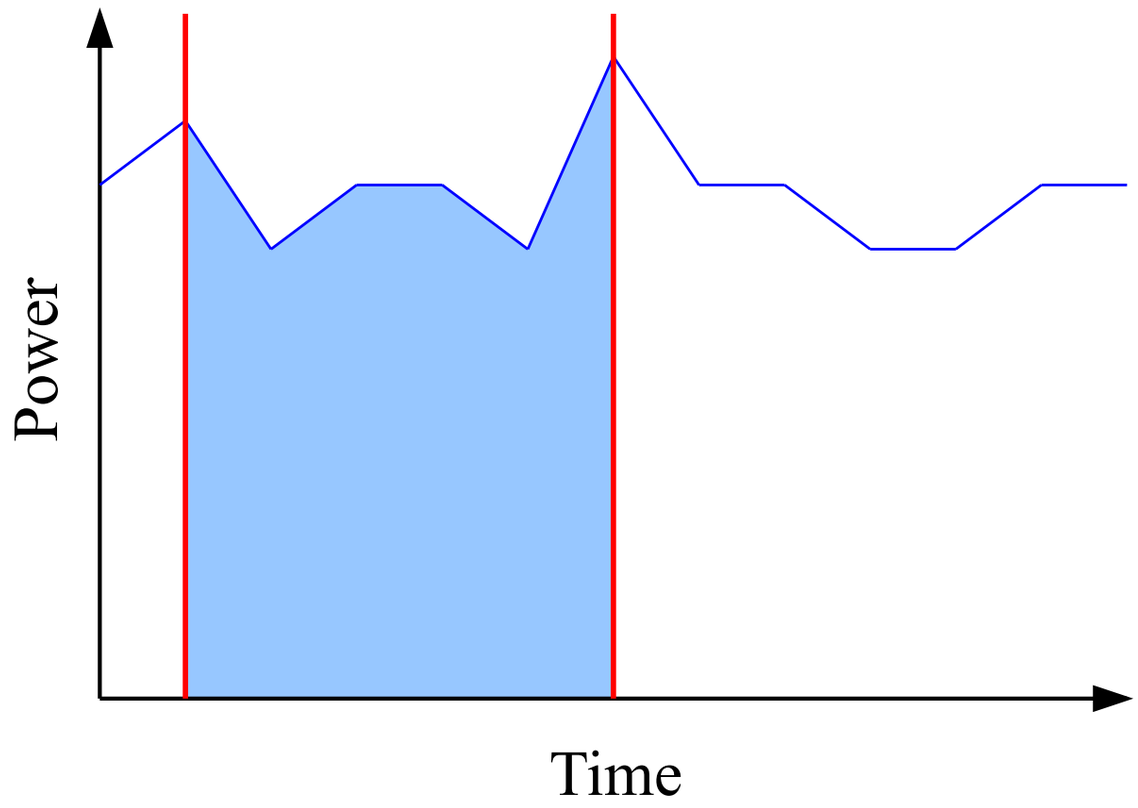
Our method

Goal: Per-frame energy

Method overview

Three main steps

- Record current and voltage
  - To get power
- Acquire timestamps
- Integrate power to energy



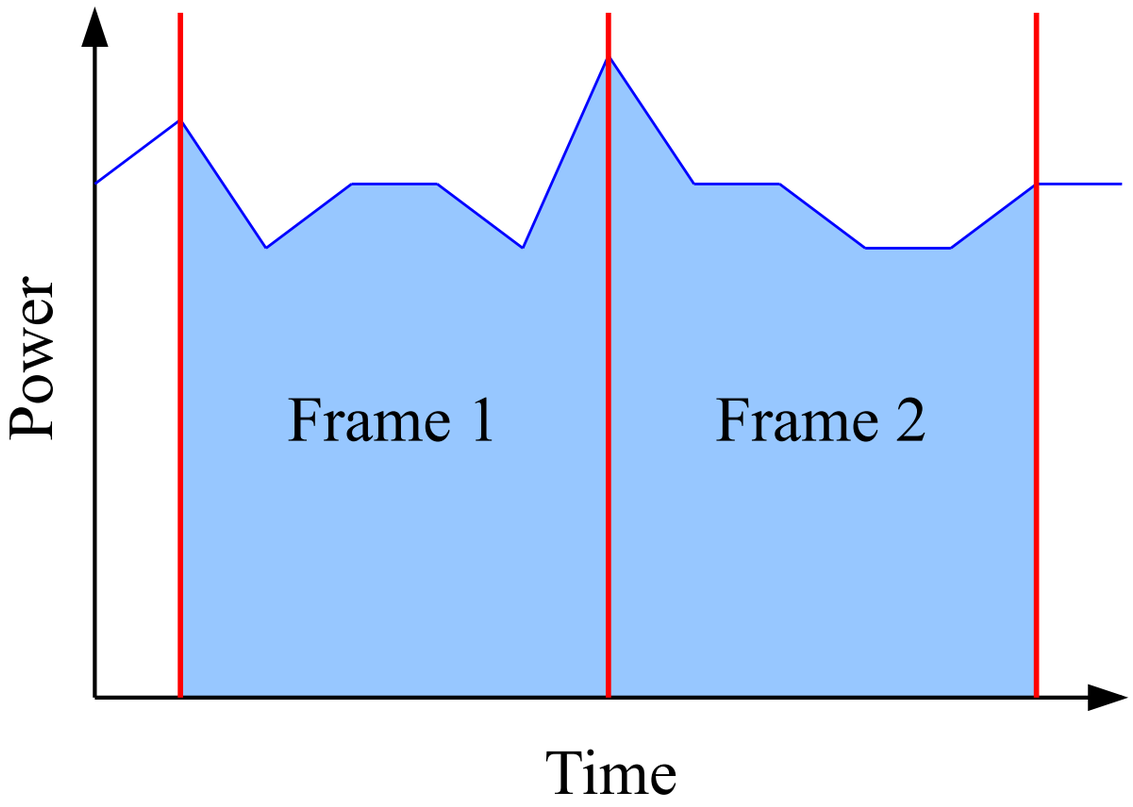
Our method

Goal: Per-frame energy

Method overview

Three main steps

- Record current and voltage
  - To get power
- Acquire timestamps
- Integrate power to energy
  - For each frame

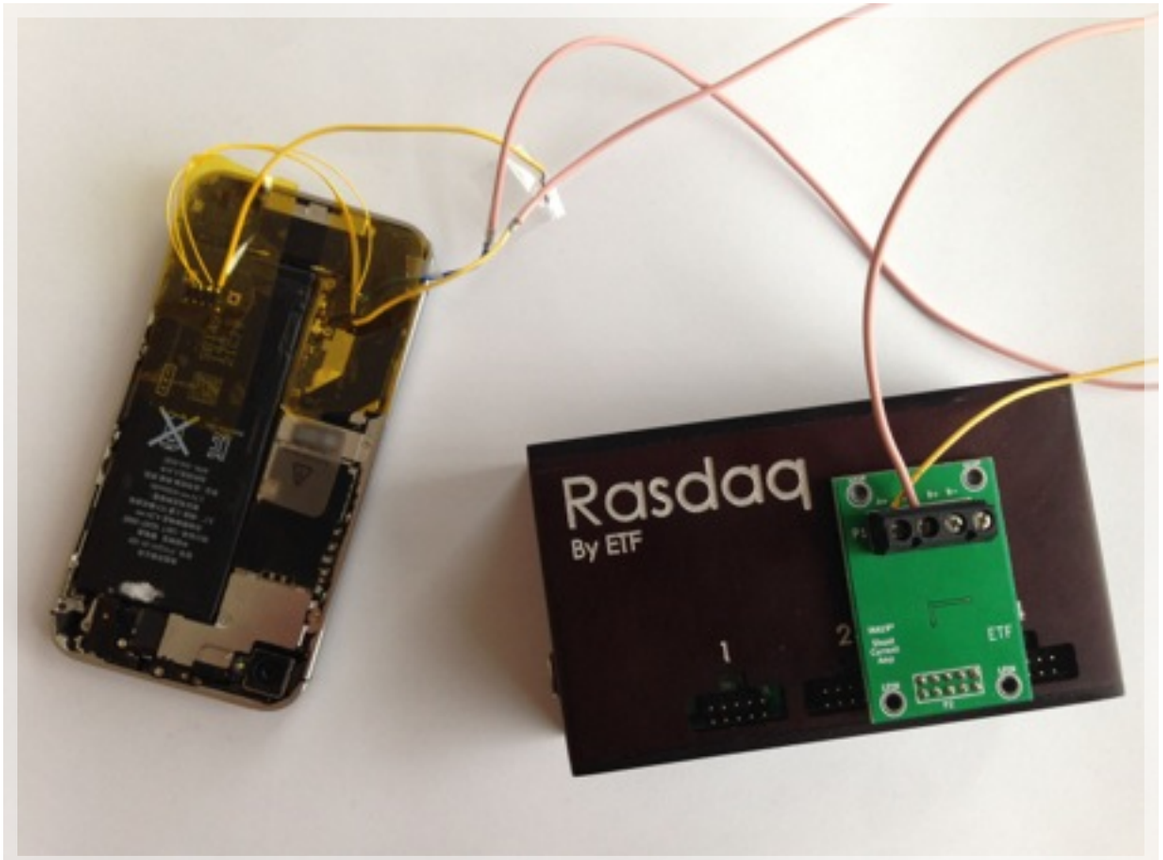


Our method

Step 1: Record current and voltage

Recording

- High frequency Data Acquisition Device (DAQ)

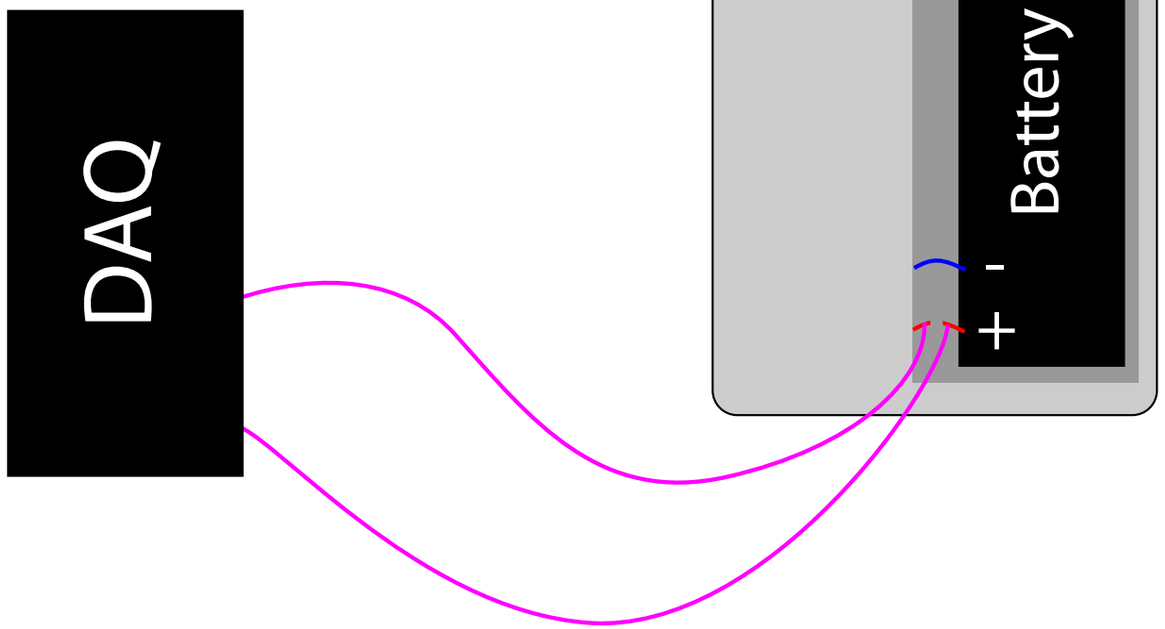


Our method

Step 1: Record current and voltage

Recording

- High frequency DAQ
- Point of connection
  - What is measured?
  - What is not measured?



Our method

Step 1: Record current and voltage

Recording

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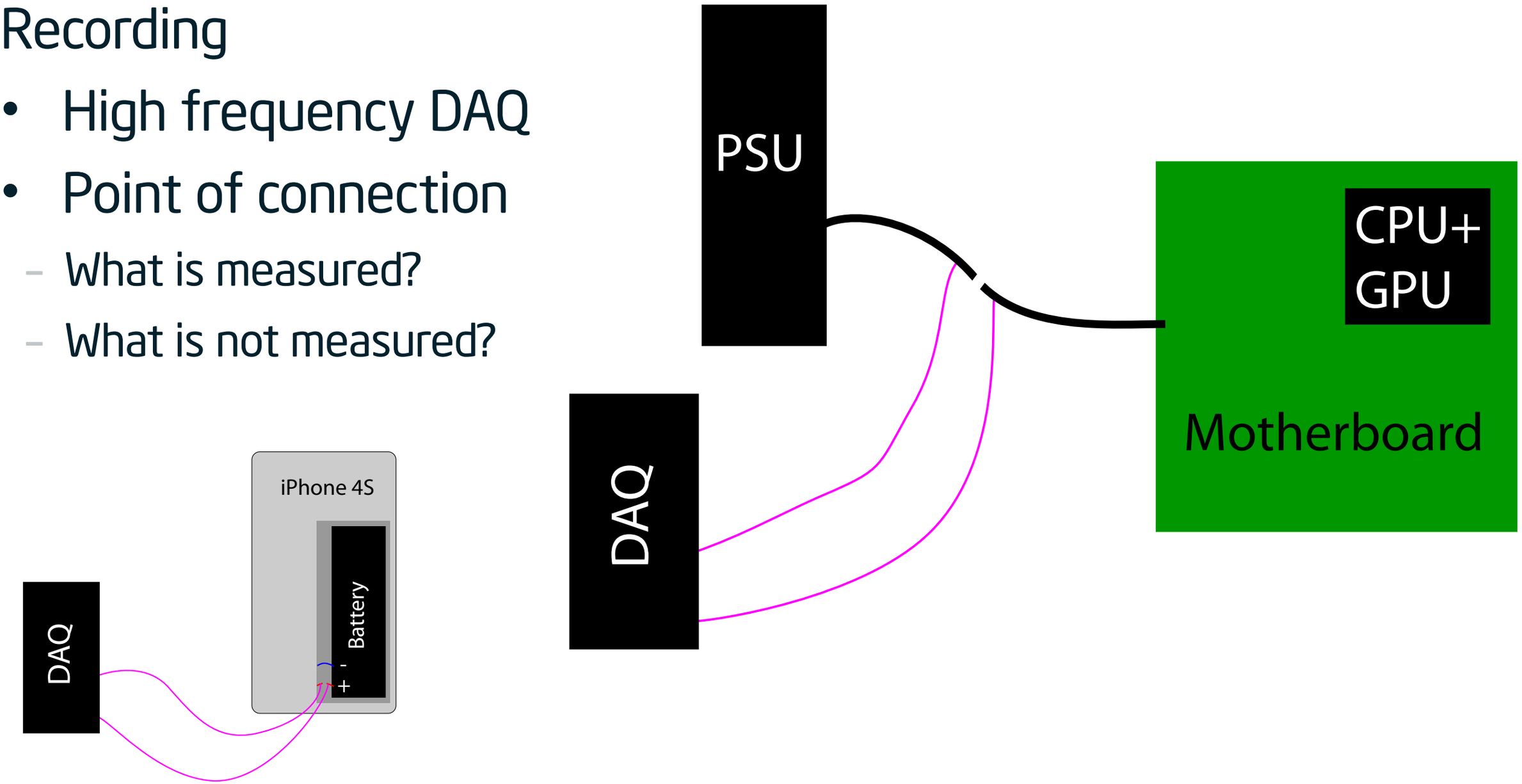

Our method

Step 1: Record current and voltage

Recording

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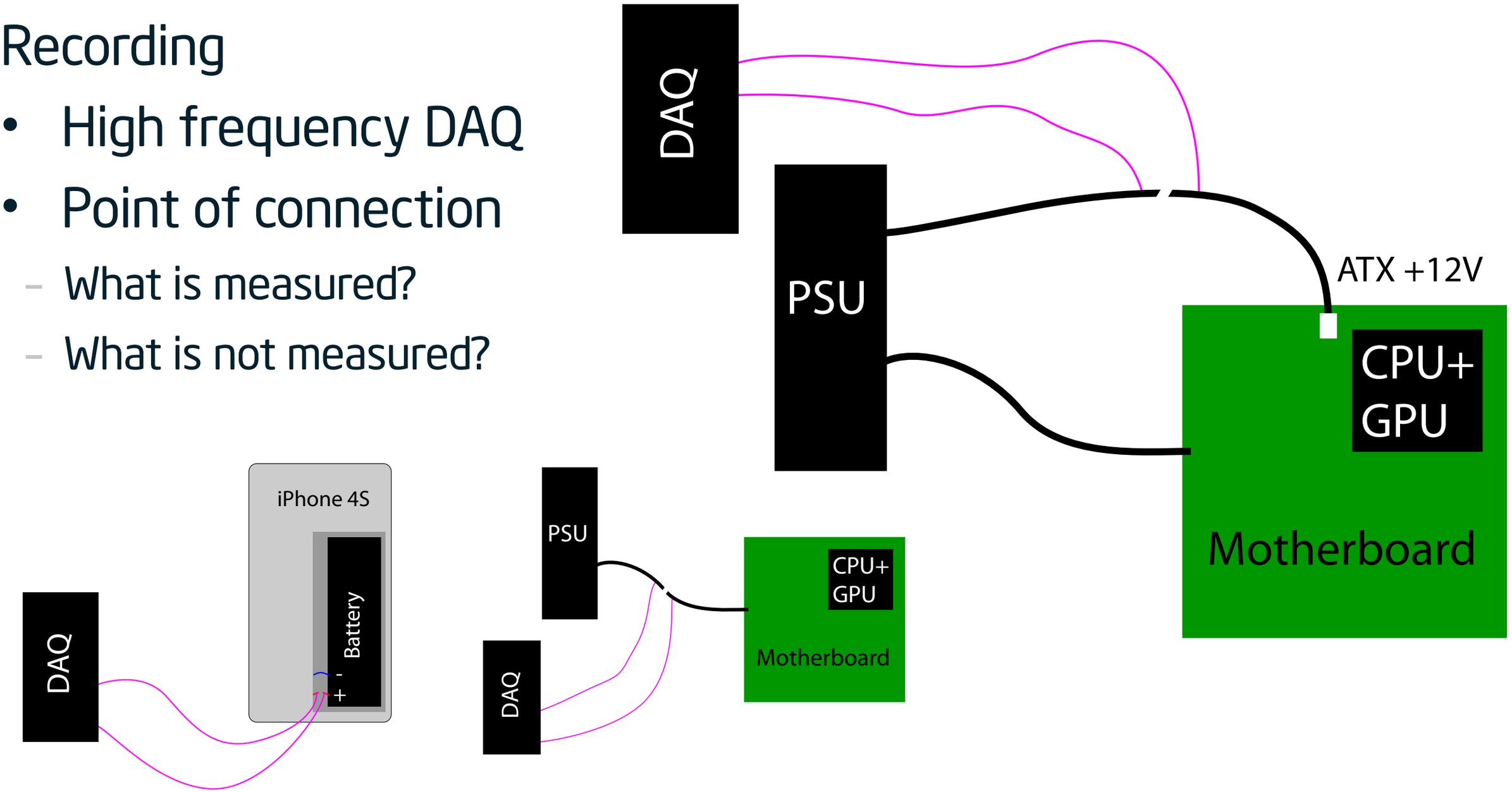

Our method

Step 1: Record current and voltage

Recording

- High frequency DAQ
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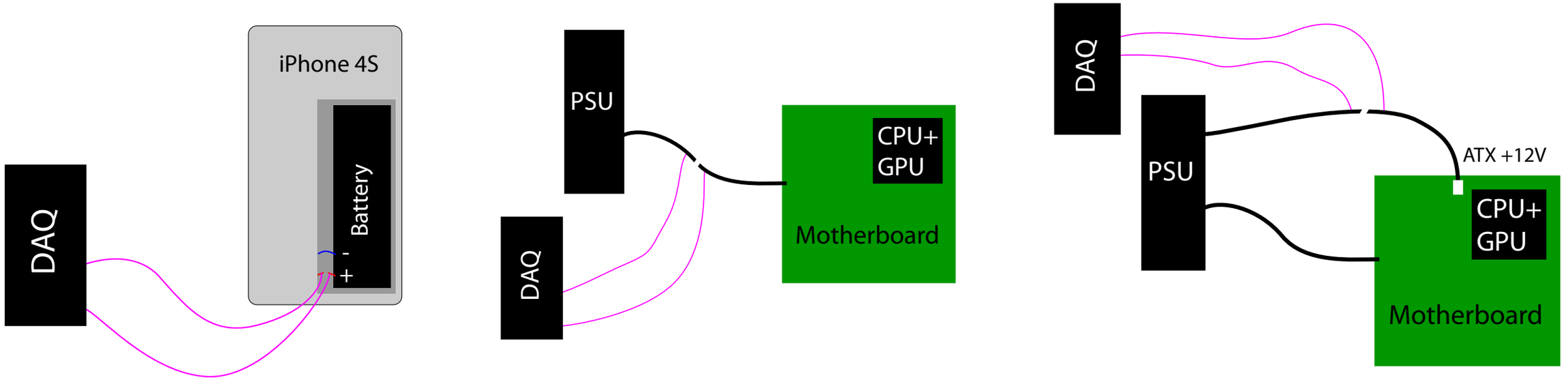
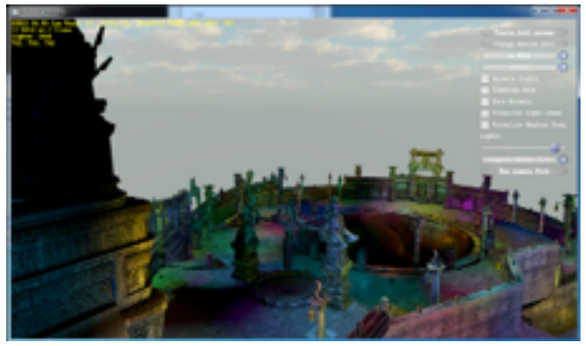
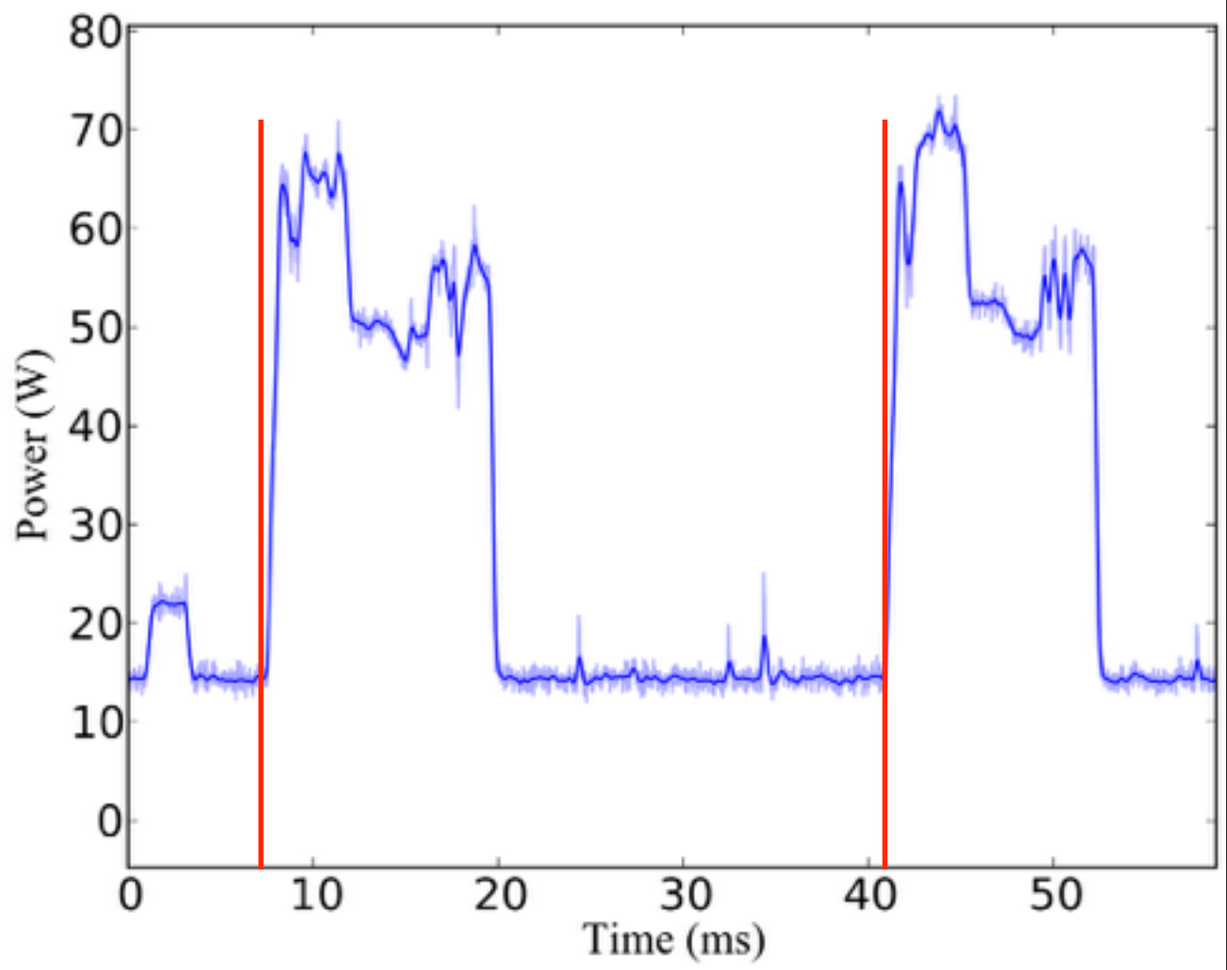


Our method

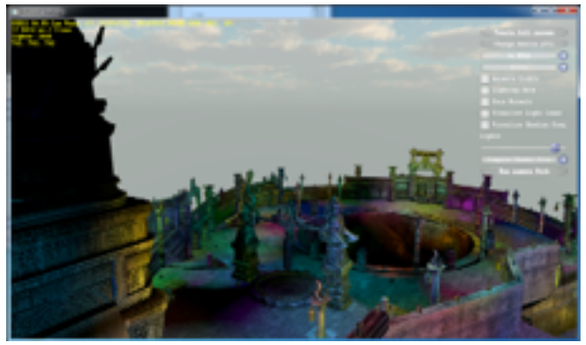


Step 2: Acquire timestamps



Intel Iris Pro

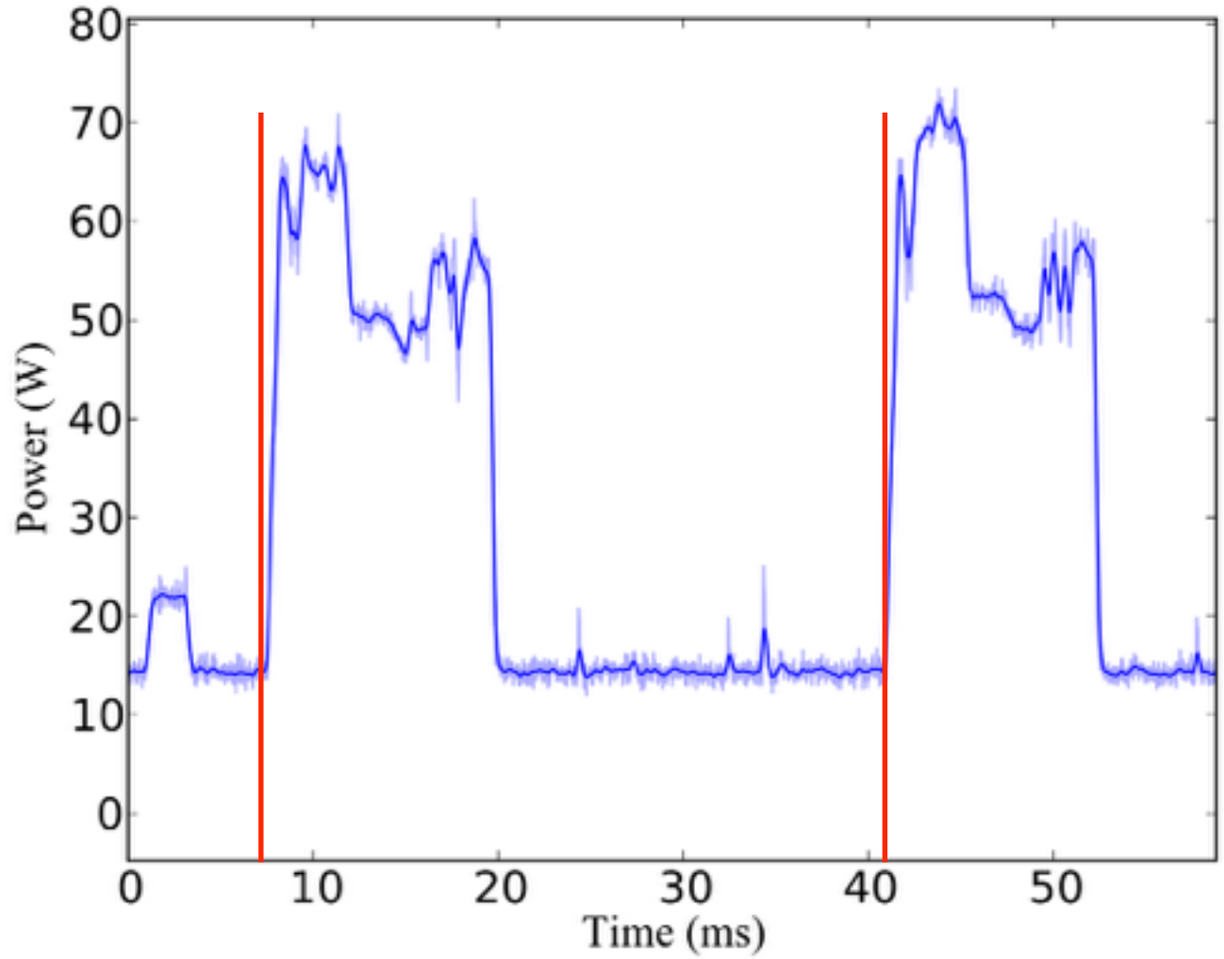
Our method



Step 2: Acquire timestamps

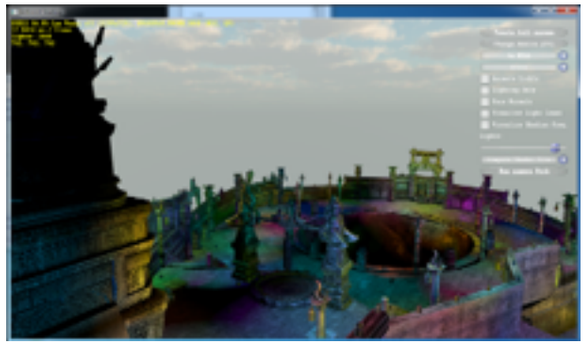
Method 1: Recording

- Altering measured workload
  - Requires source code
- Synchronization required



Intel Iris Pro

Our method



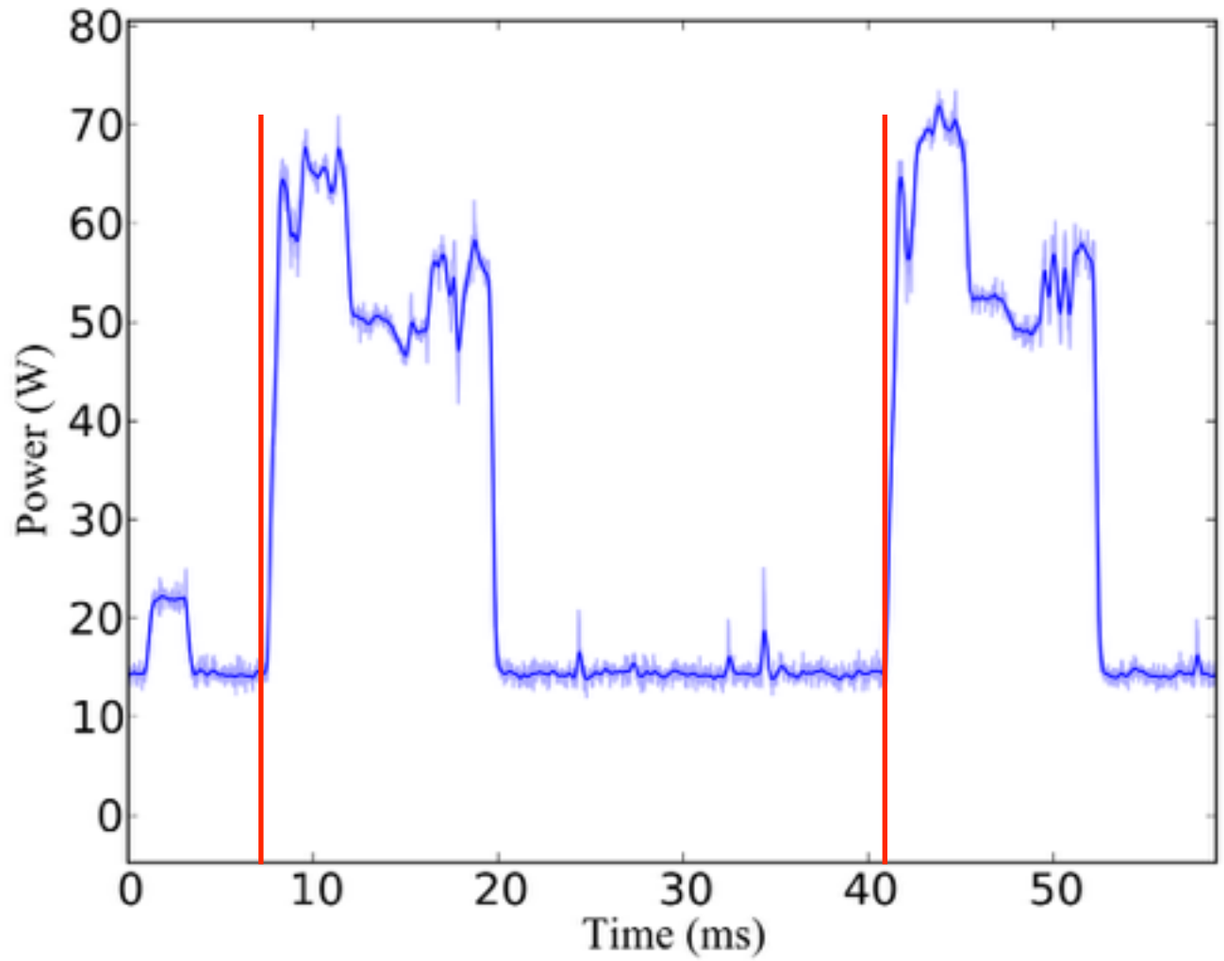
Step 2: Acquire timestamps

Method 1: Recording

- Altering measured workload
  - Requires source code
- Synchronization required

Method 2: Detect frame starts

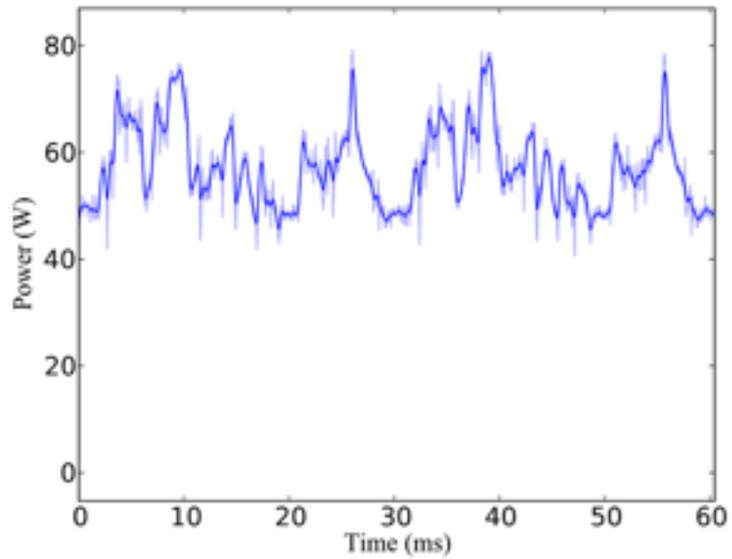
- Detect in curve
  - Semi-automatic
  - Works without source code



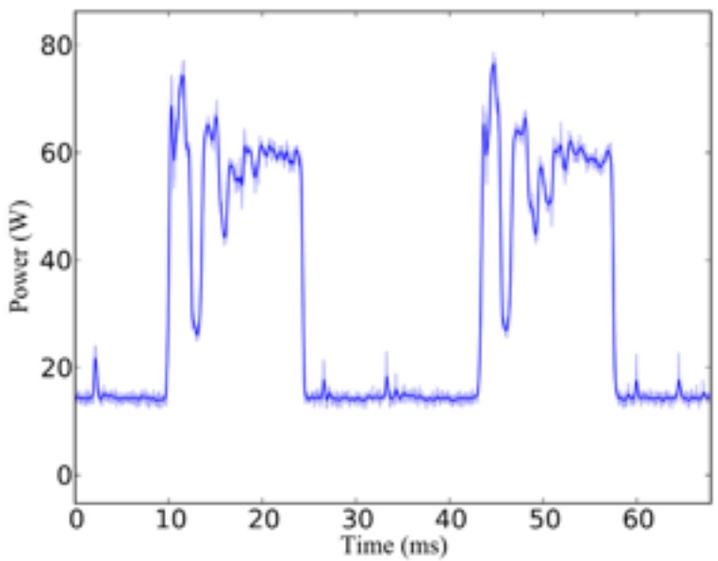
Intel Iris Pro

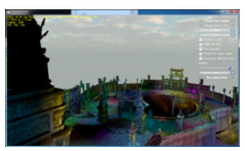
Our method

Detecting frame starts

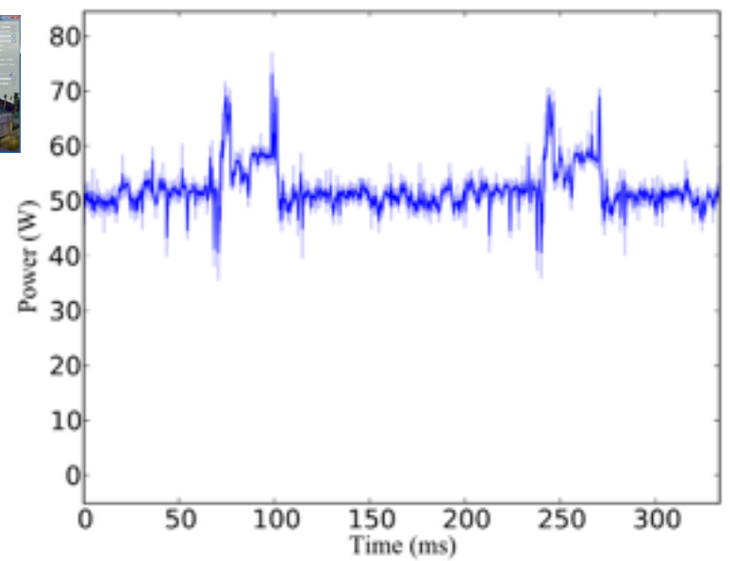


Intel Iris Pro





Intel Iris Pro

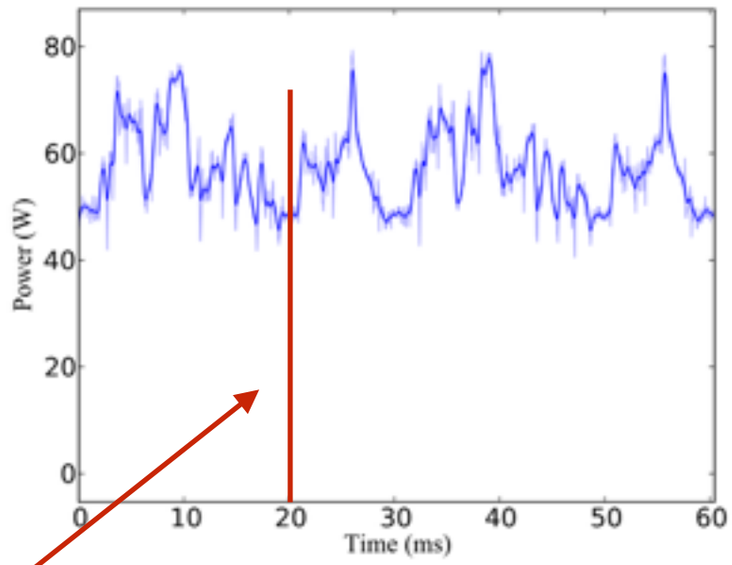


Intel Iris Pro

Our method

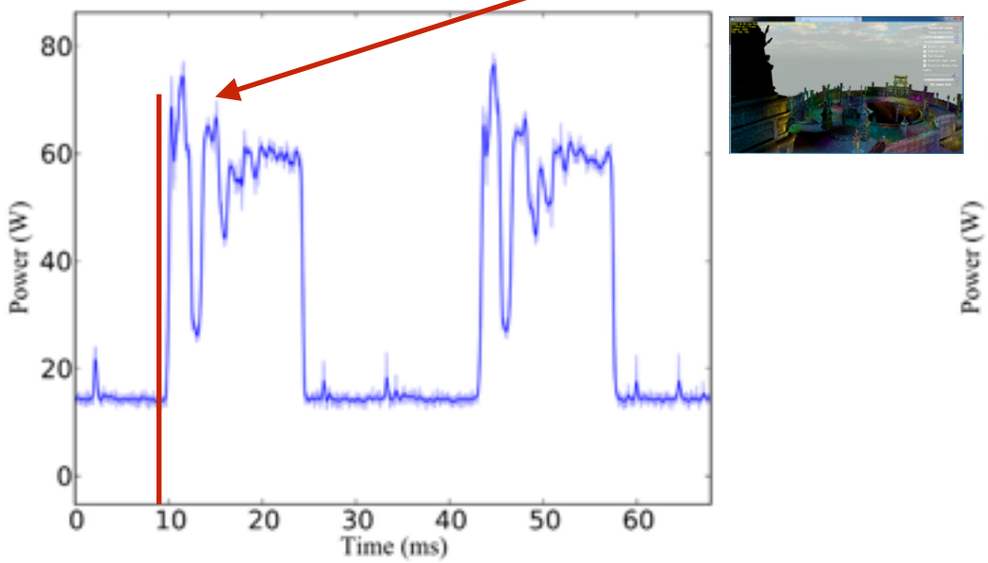
Detecting frame starts

- Visually detect and mark

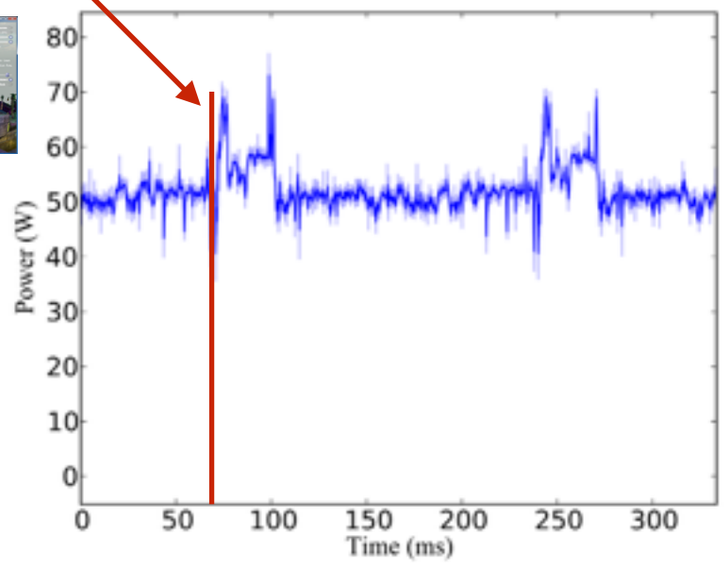


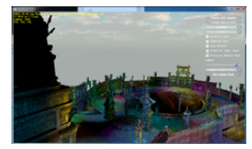
Mark

Intel Iris Pro



Intel Iris Pro



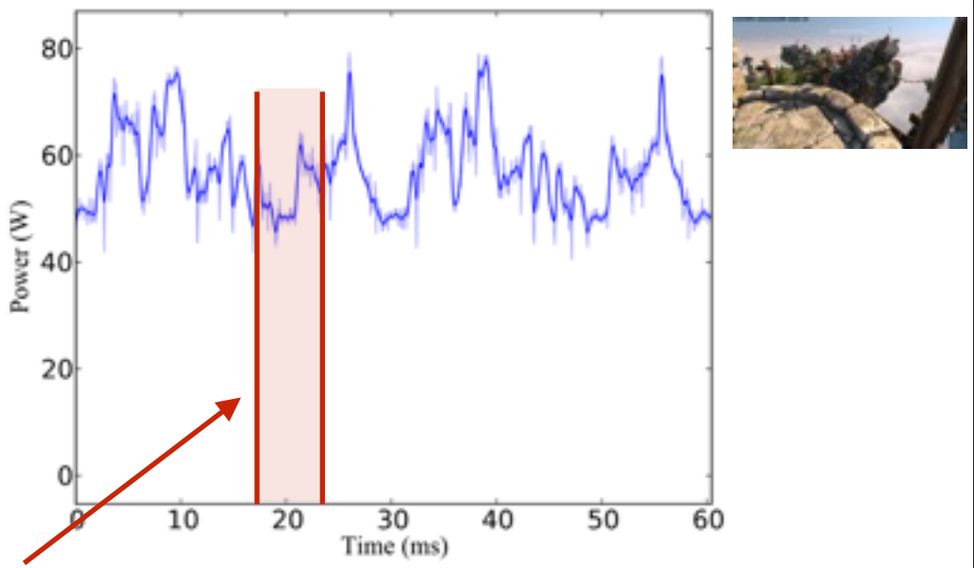


Intel Iris Pro

Our method

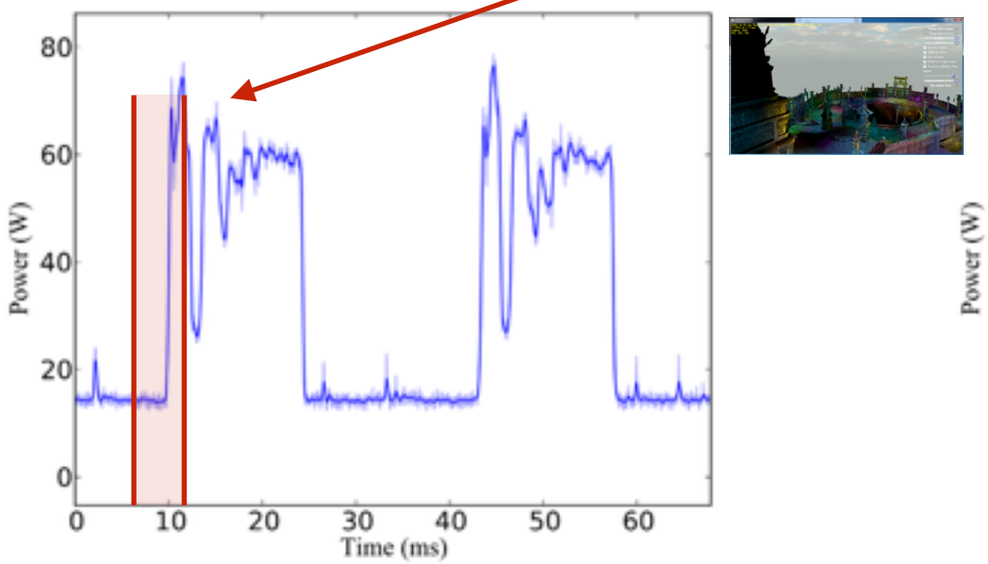
Detecting frame starts

- Visually detect and mark
- Record surrounding

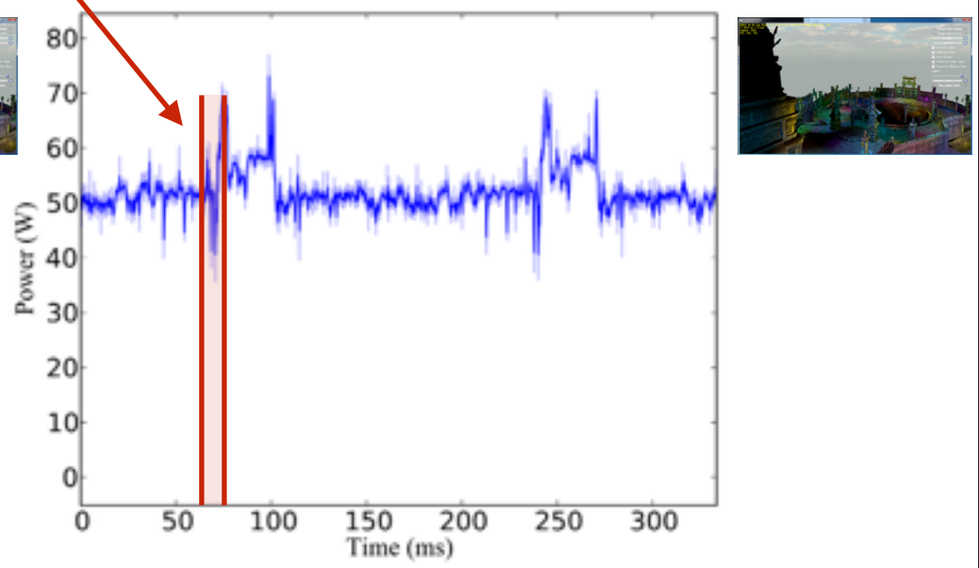


Intel Iris Pro

Record



Intel Iris Pro

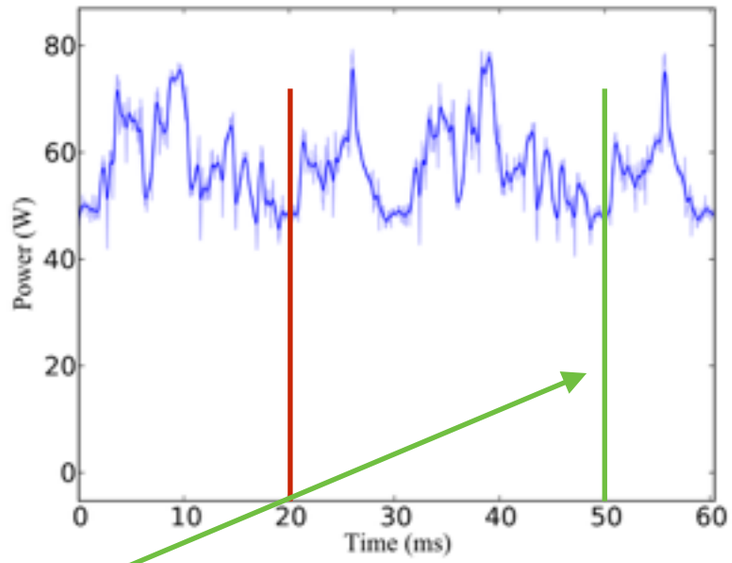


Intel Iris Pro

Our method

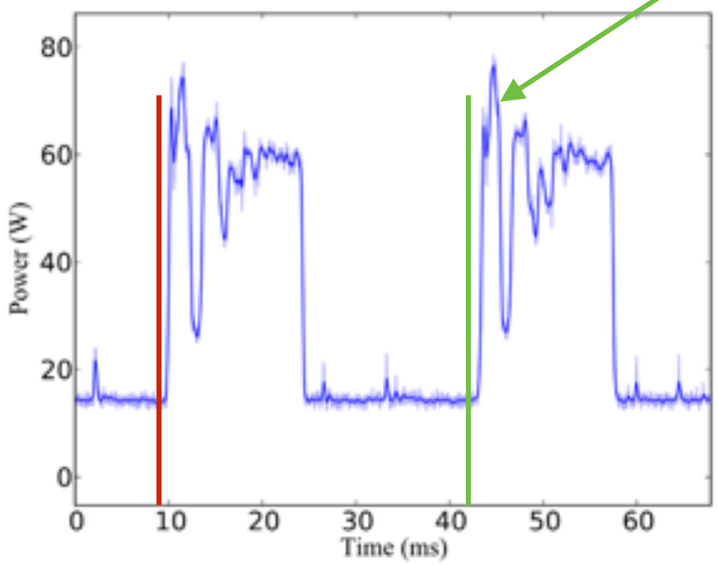
Detecting frame starts

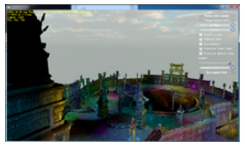
- Visually detect and mark
- Record surrounding
- Search for similar areas using LSE



Found

Intel Iris Pro





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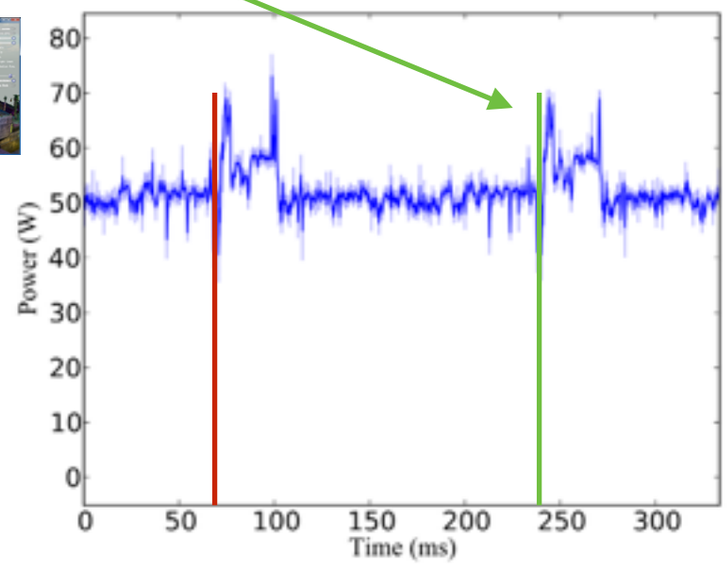

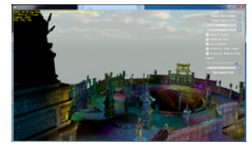

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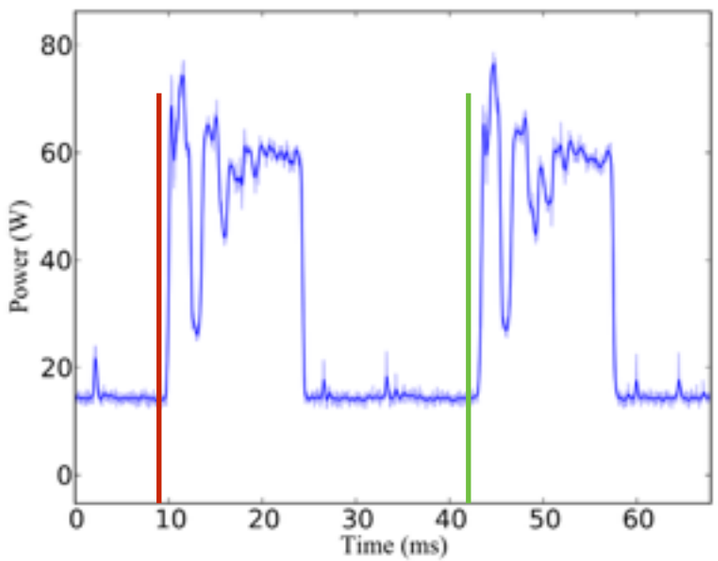
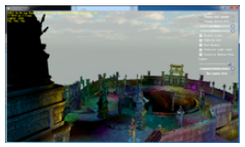
Our method

Detecting frame starts

- Where does the frame start?

Intel Iris Pro





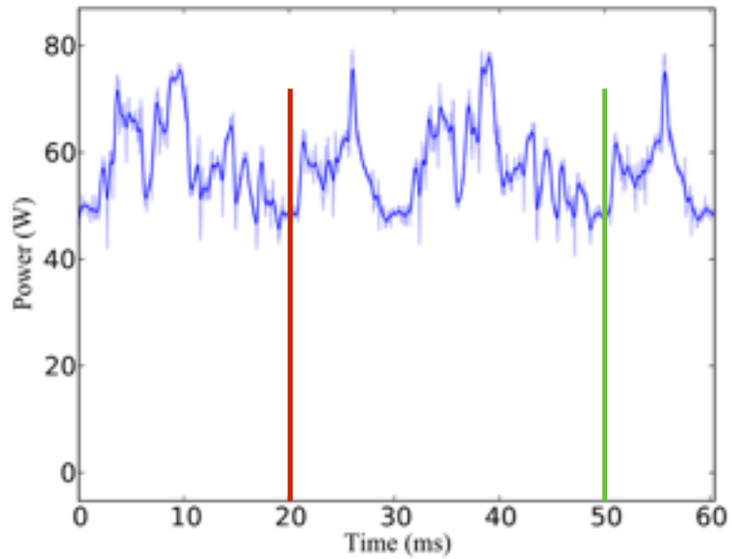
Intel Iris Pro

Intel Iris Pro

Our method

Detecting frame starts

- Where does the frame start?



Intel Iris Pro

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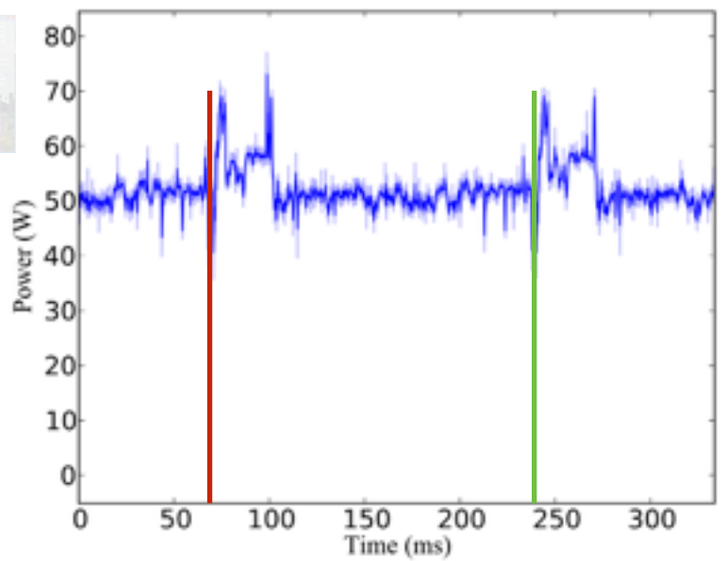
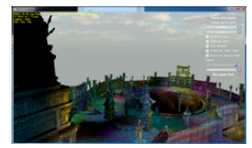




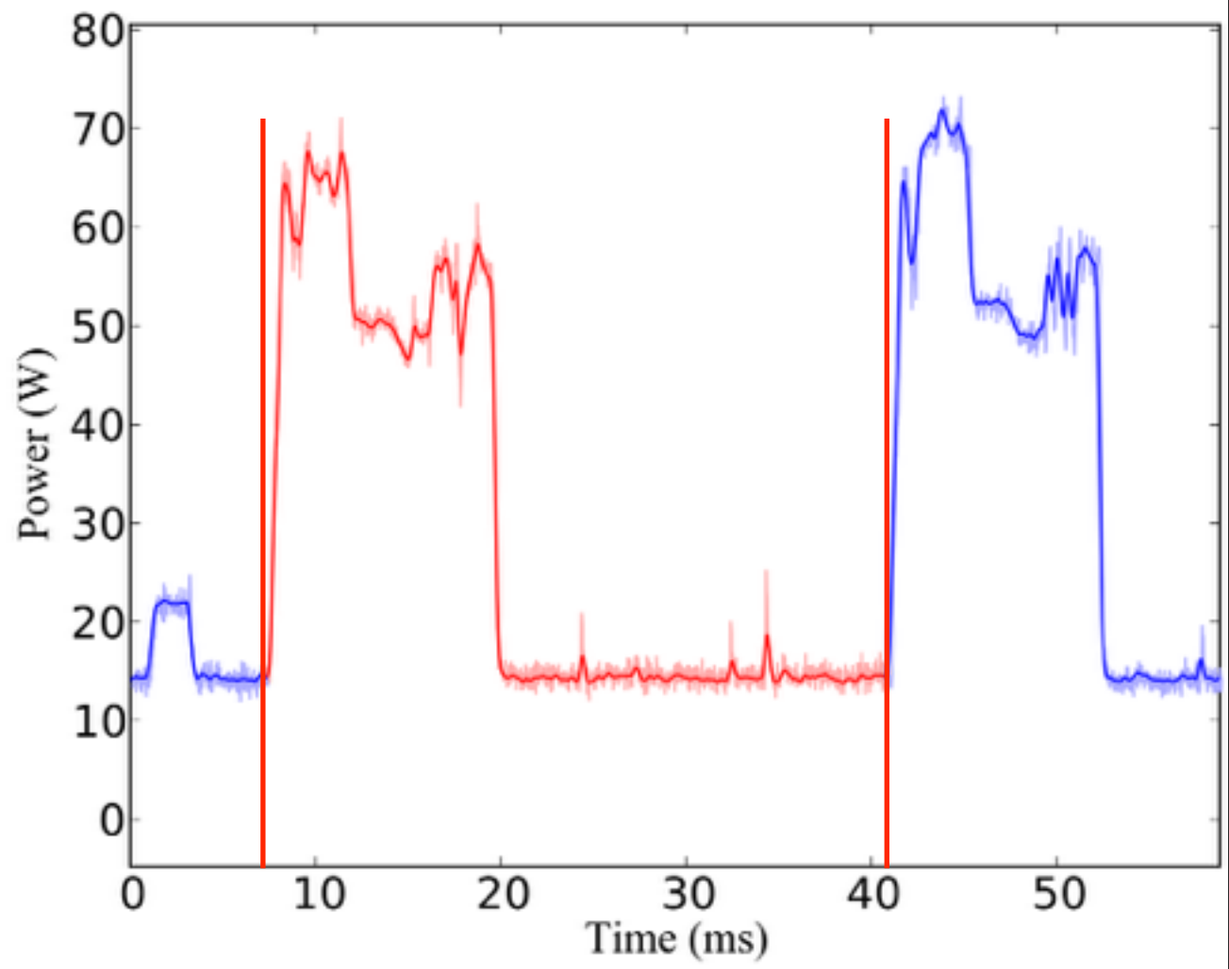
Intel Iris Pro

Our method

Step 3: Integrate energy

Integrate between timestamps

$$E = \frac{\sum_{t=start}^{end} P_t}{f}$$



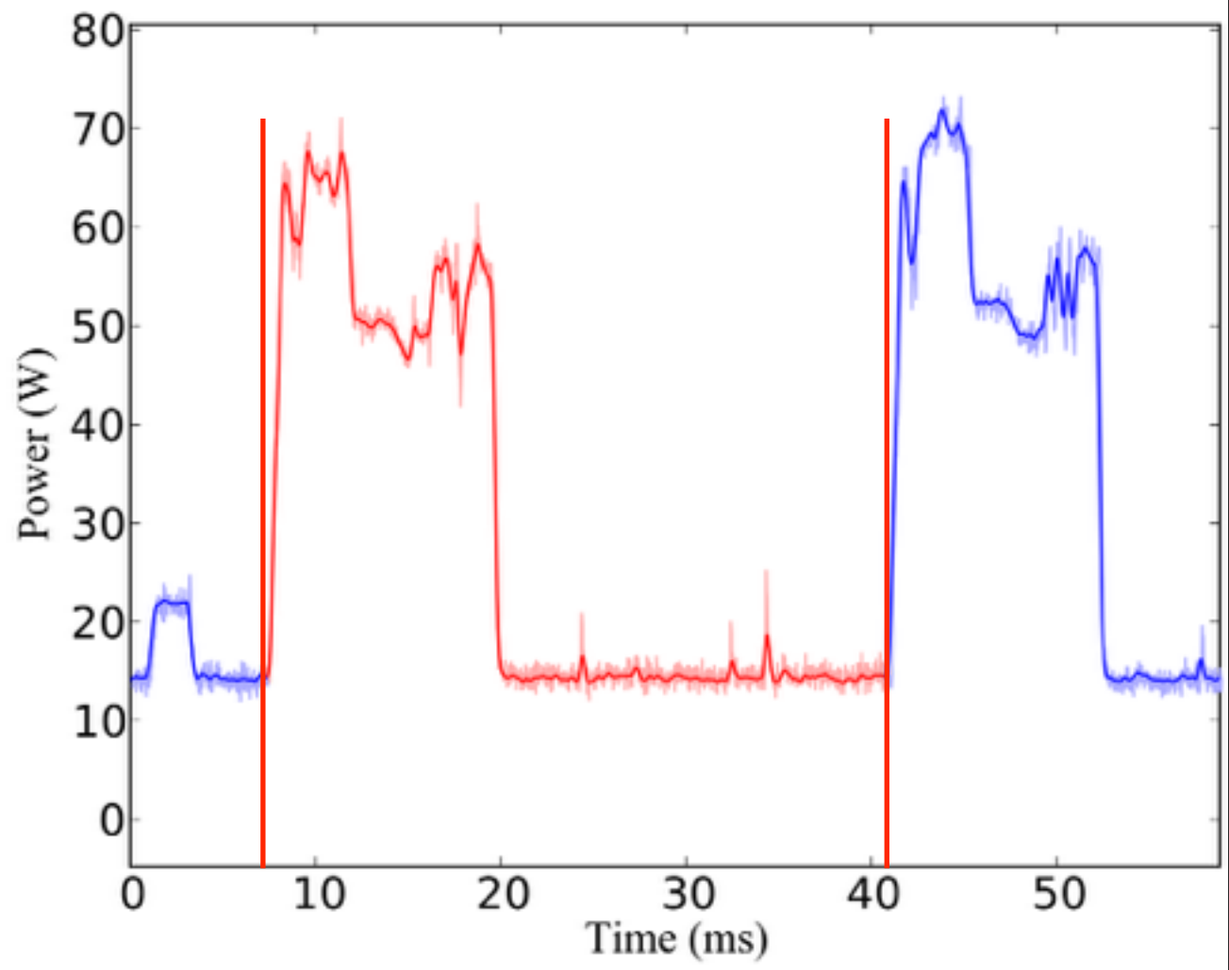
Intel Iris Pro

Our method

Step 3: Integrate energy

Integrate between timestamps

$$E = \frac{\sum_{t=start}^{end} P_t}{f} \approx \int P(t)\,dt$$



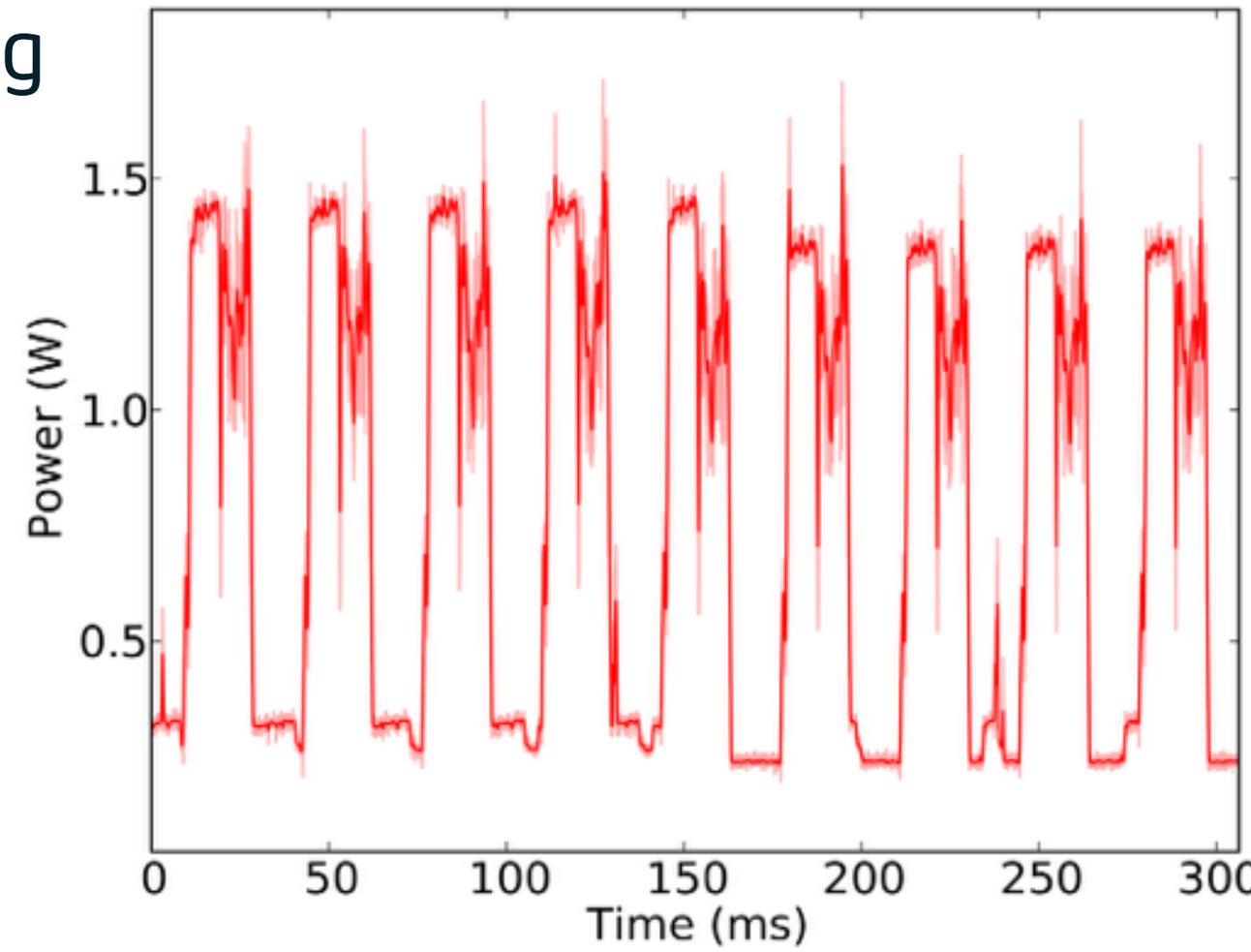
Intel Iris Pro

Observations

Observations

Application launch

- First few seconds of rendering

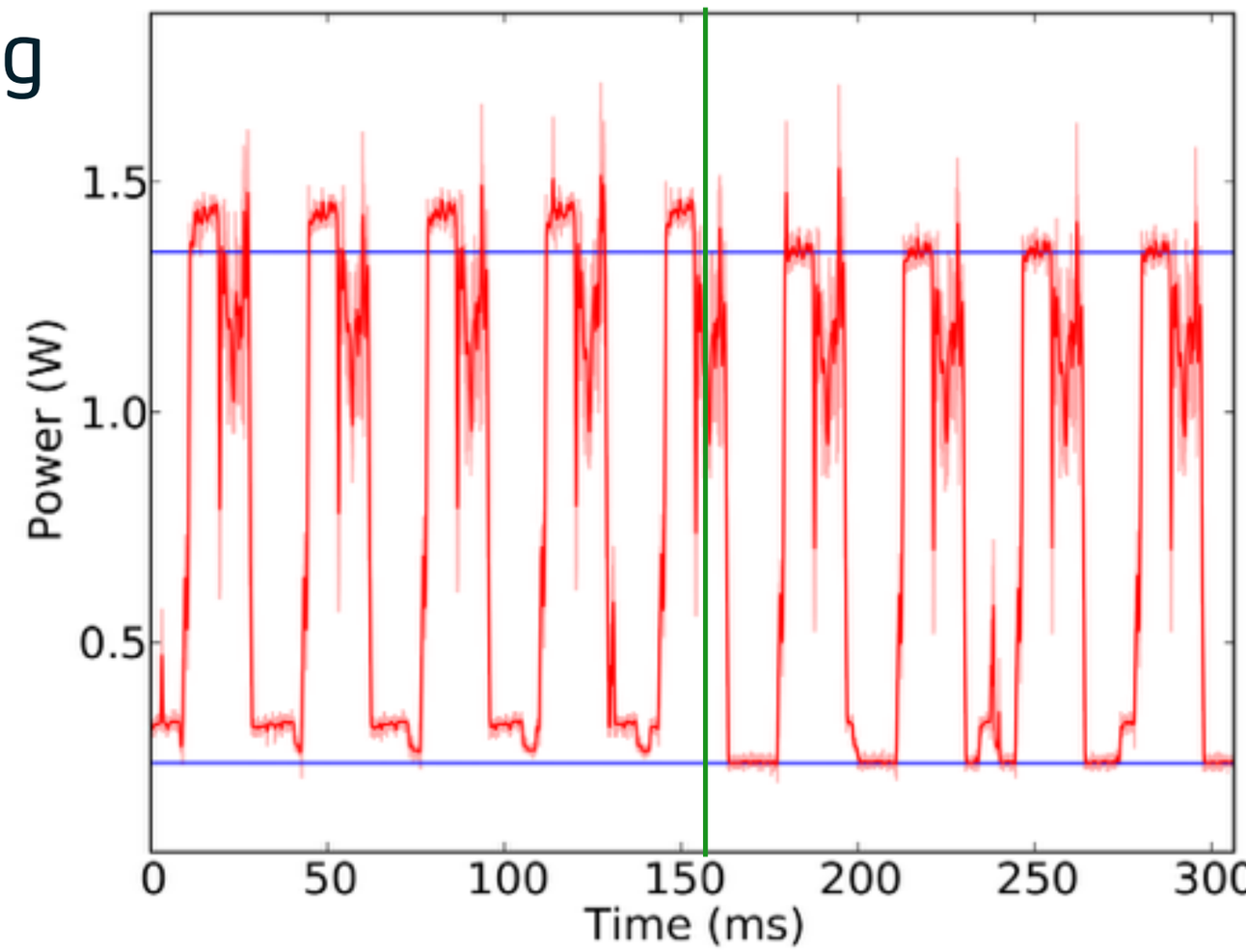


iPhone 4S

Observations

Application launch

- First few seconds of rendering
- Significantly higher power

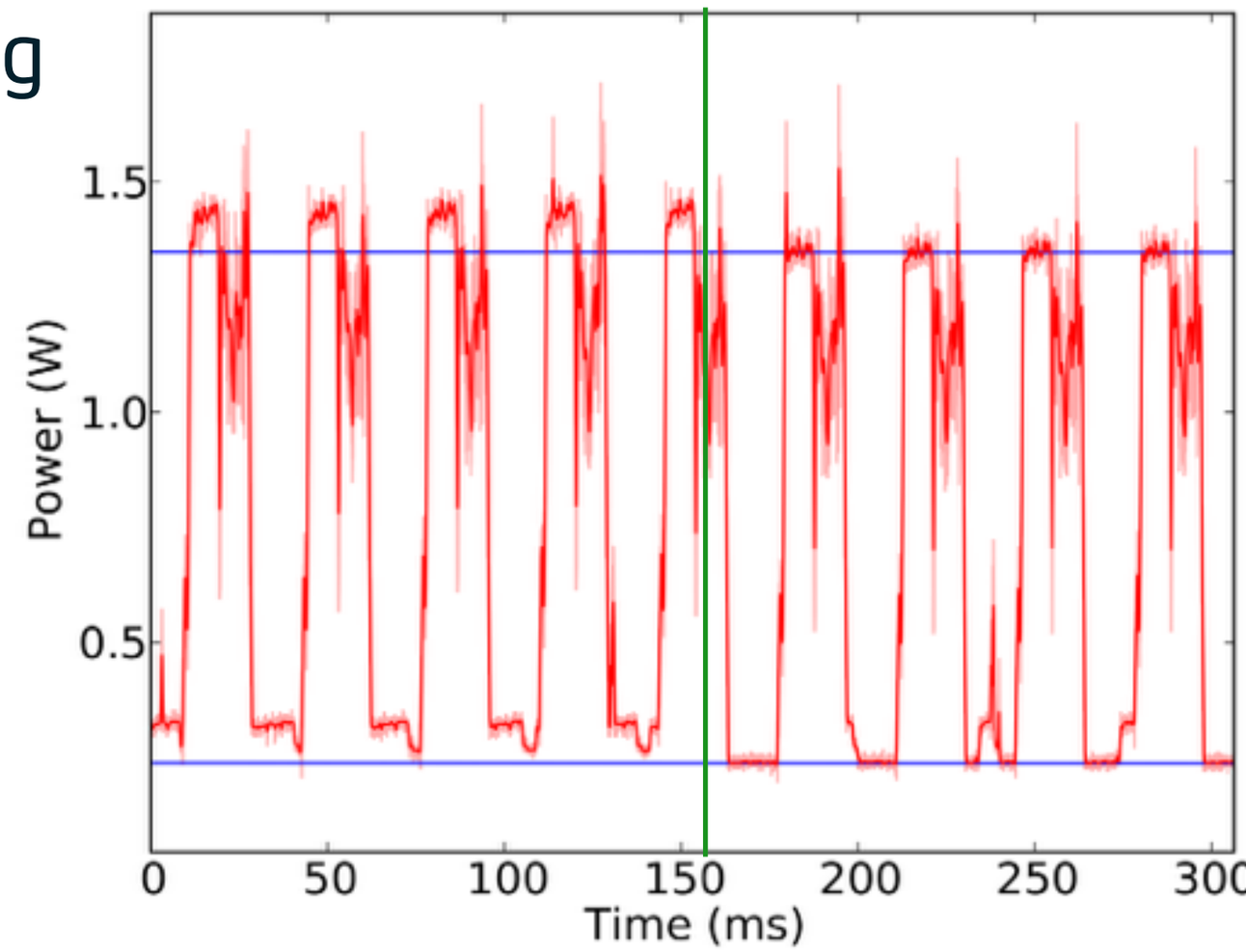


iPhone 4S

Observations

Application launch

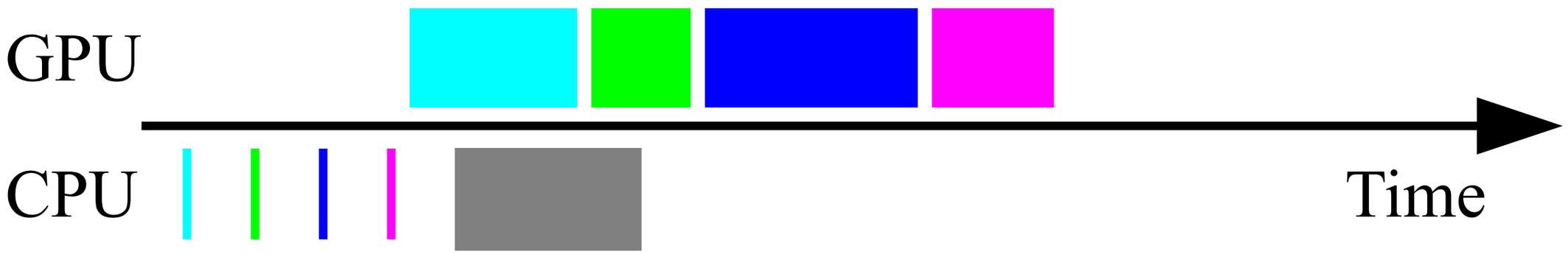
- First few seconds of rendering
- Significantly higher power
  - 5-10% higher
  - Both load and idle



iPhone 4S

Observations

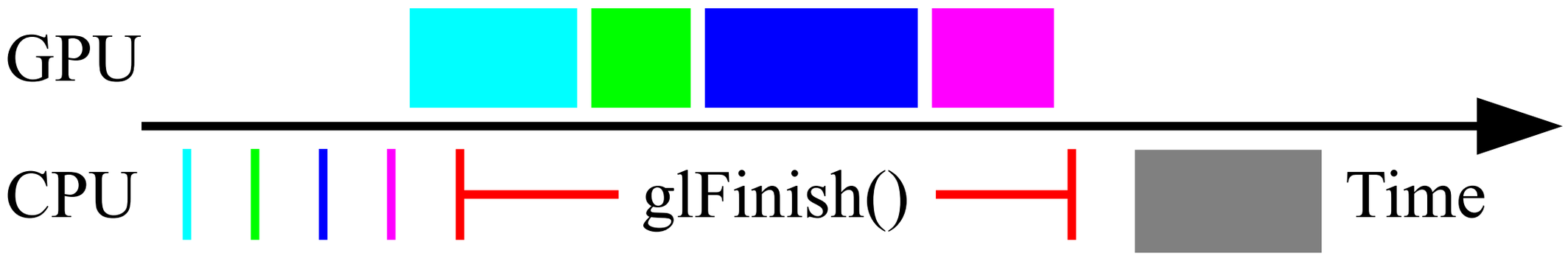
glFinish()



Observations

glFinish()

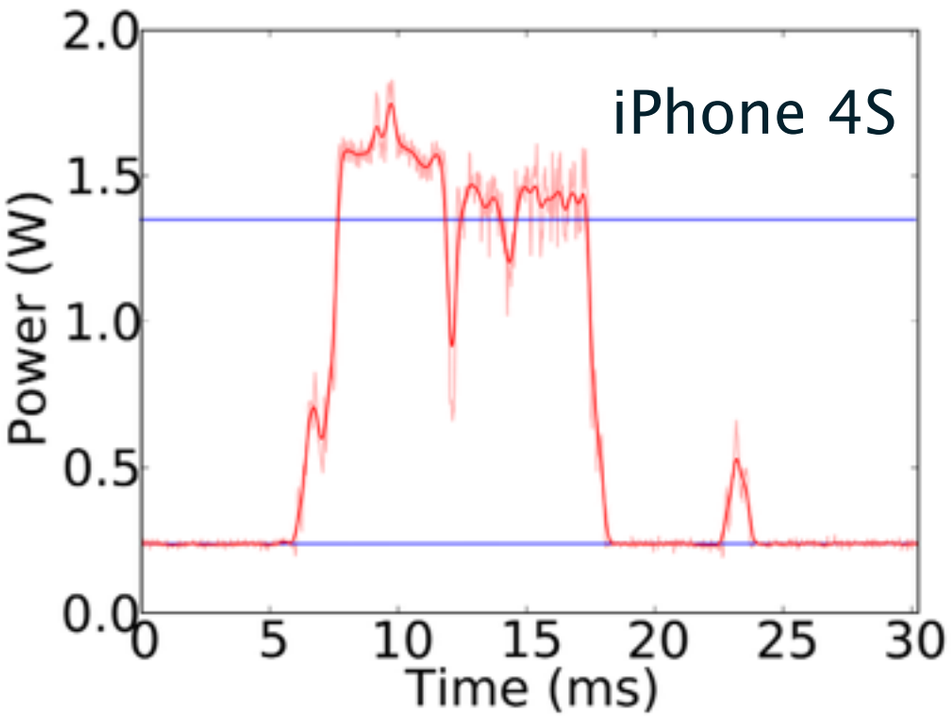
- Blocks the application until commands are finished



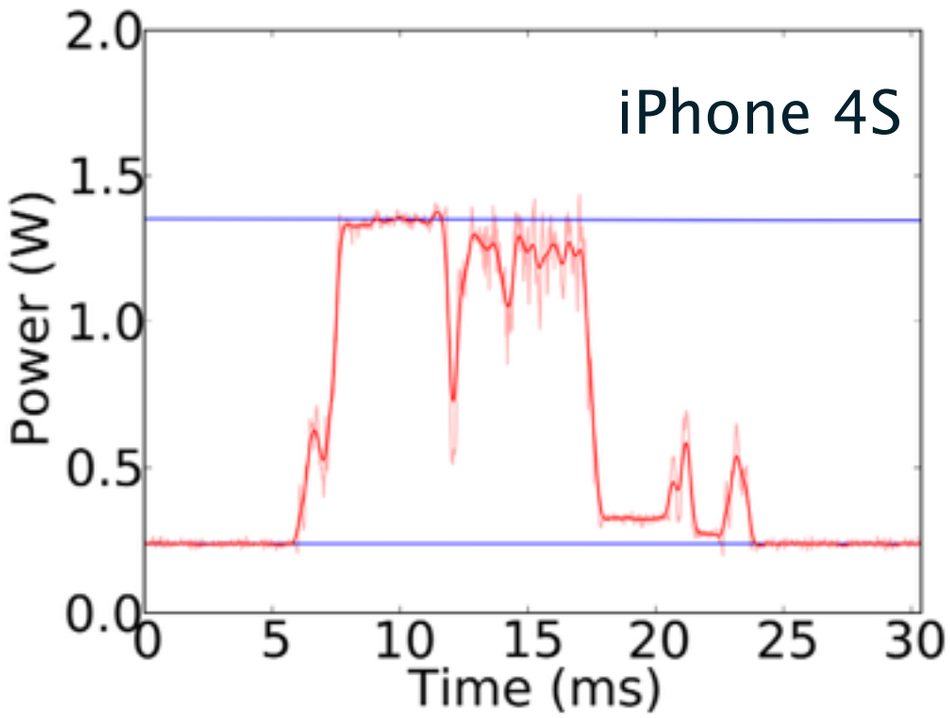
Observations

glFinish()

- Blocks the application until commands are finished
- Raises the power



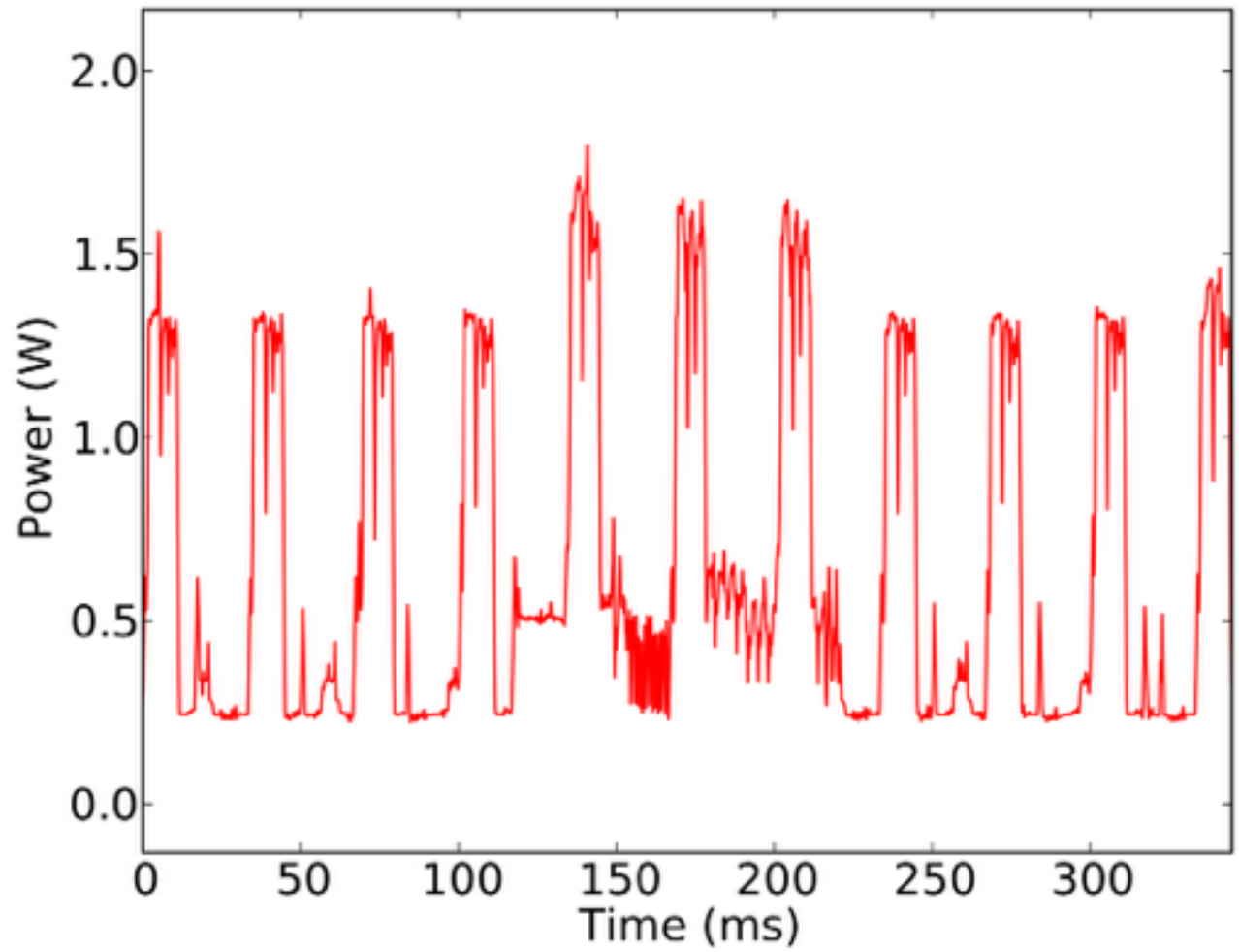
With glFinish()



Without glFinish()

Observations

Disturbance by Operating System

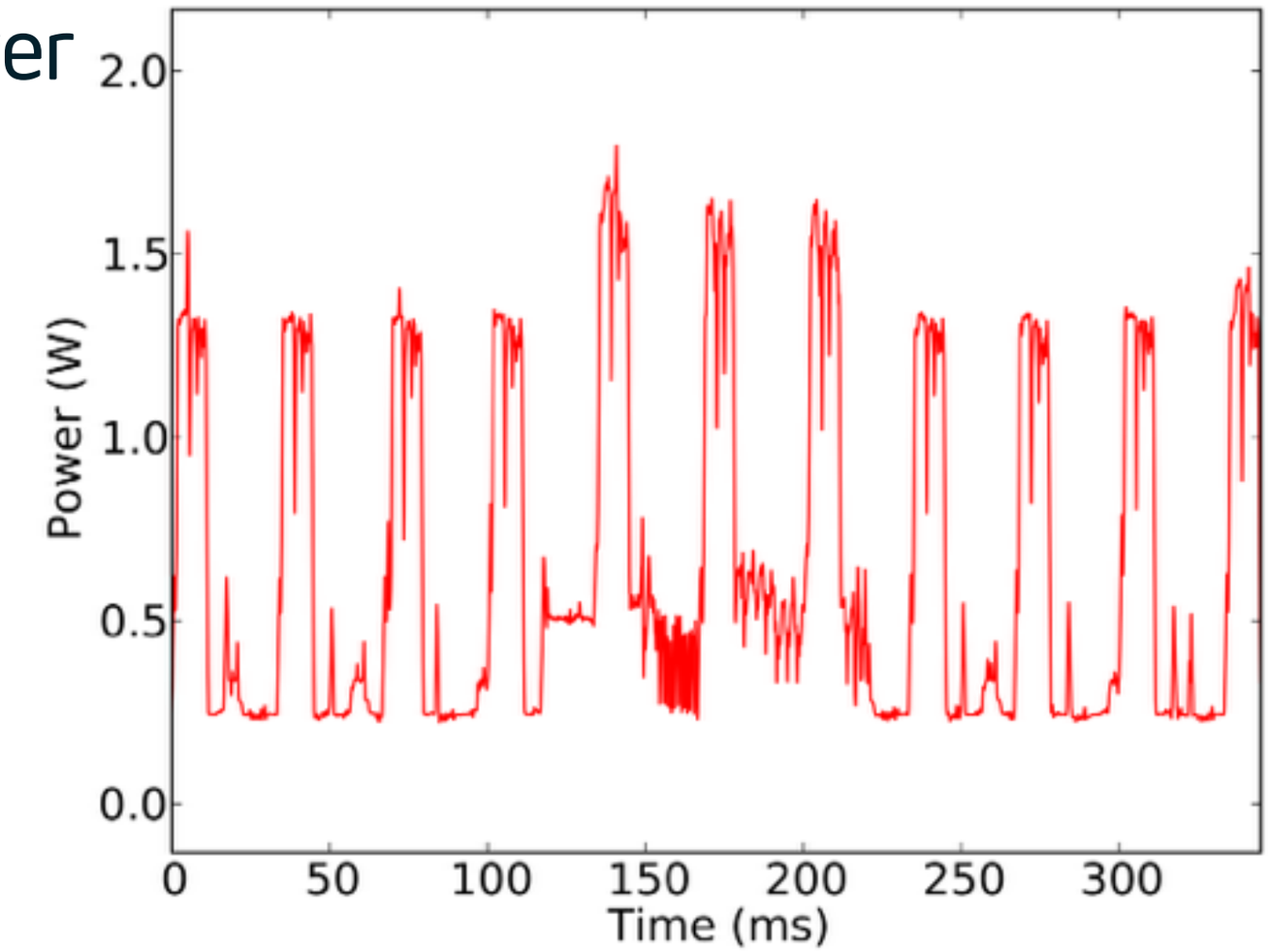


iPhone 4S

Observations

Disturbance by Operating System

- Few frames with higher power

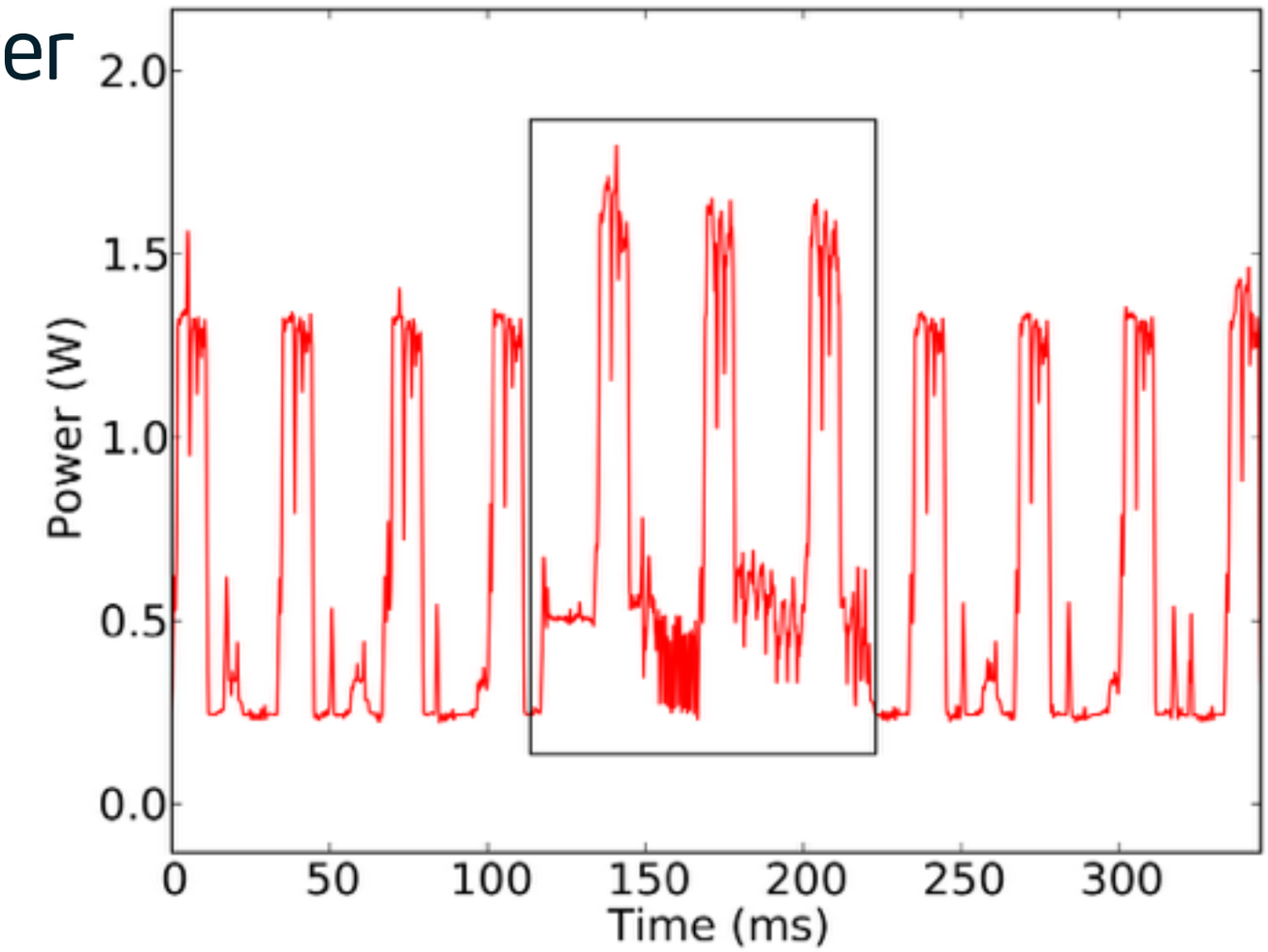


iPhone 4S

Observations

Disturbance by Operating System

- Few frames with higher power
- 90ms every 5s

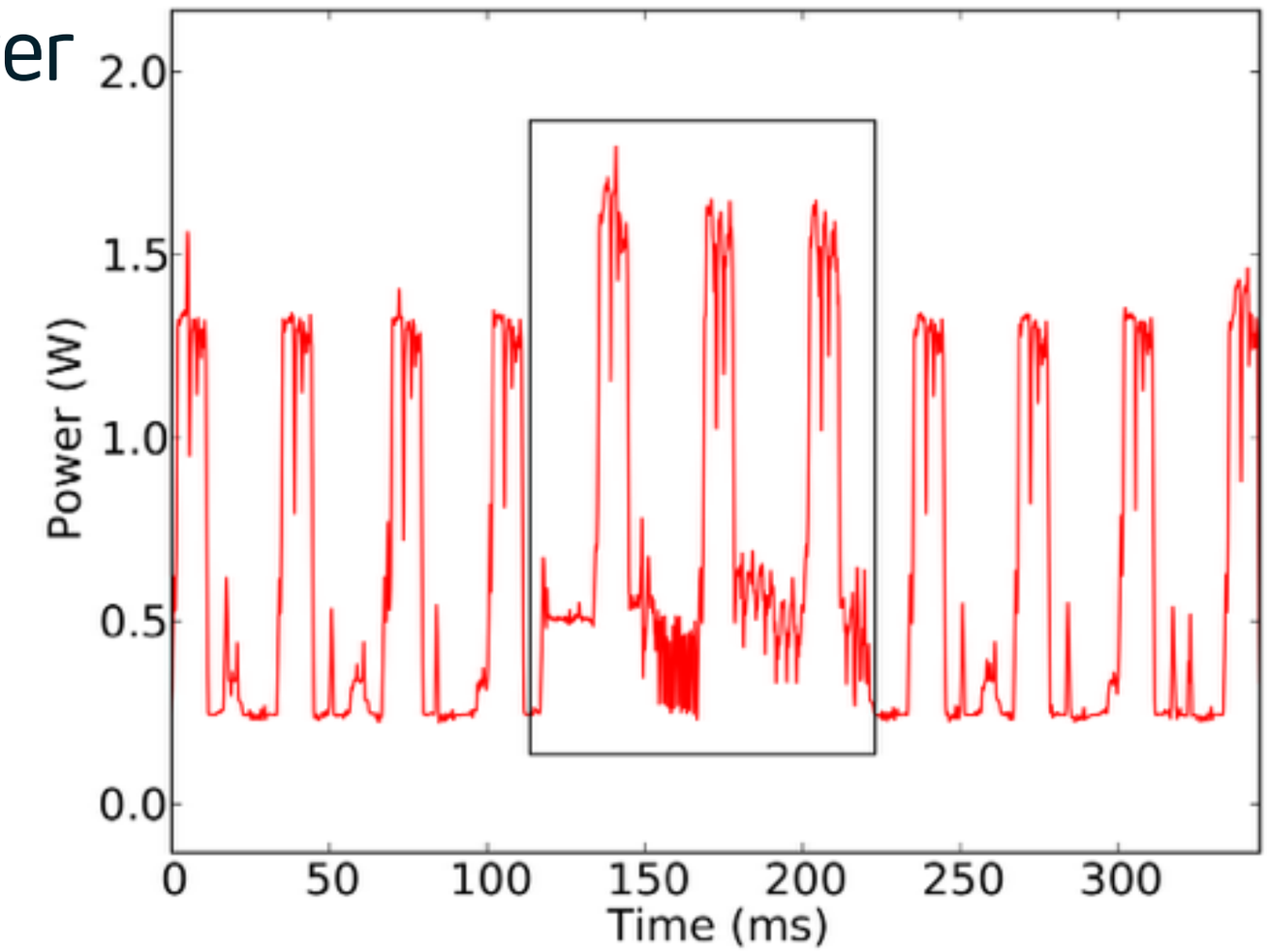


iPhone 4S

Observations

Disturbance by Operating System

- Few frames with higher power
- 90ms every 5s
  - Same pattern without app running



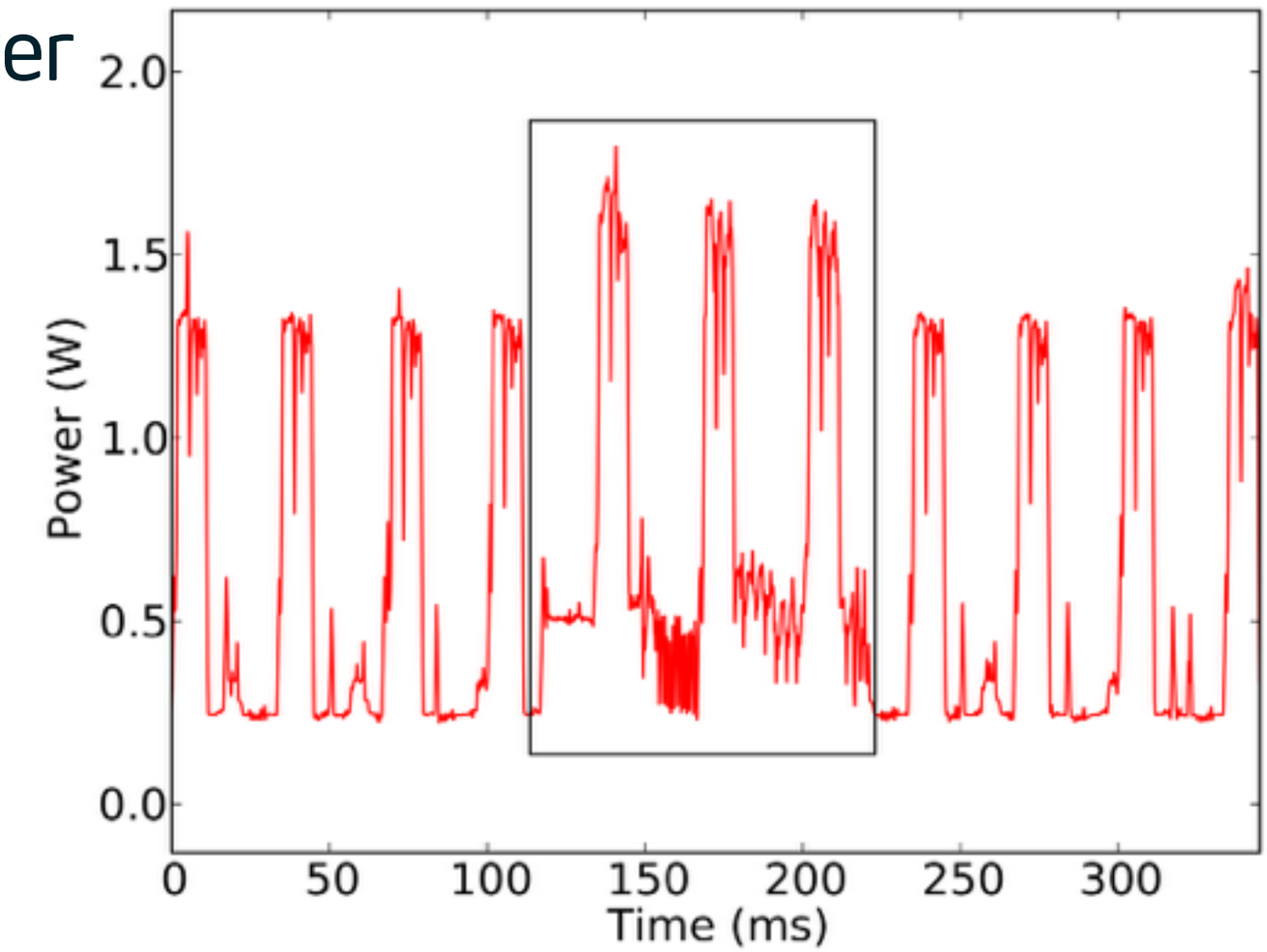
iPhone 4S

Observations

Disturbance by Operating System

- Few frames with higher power
- 90ms every 5s
  - Same pattern without app running

Similar disturbances on most platforms



iPhone 4S

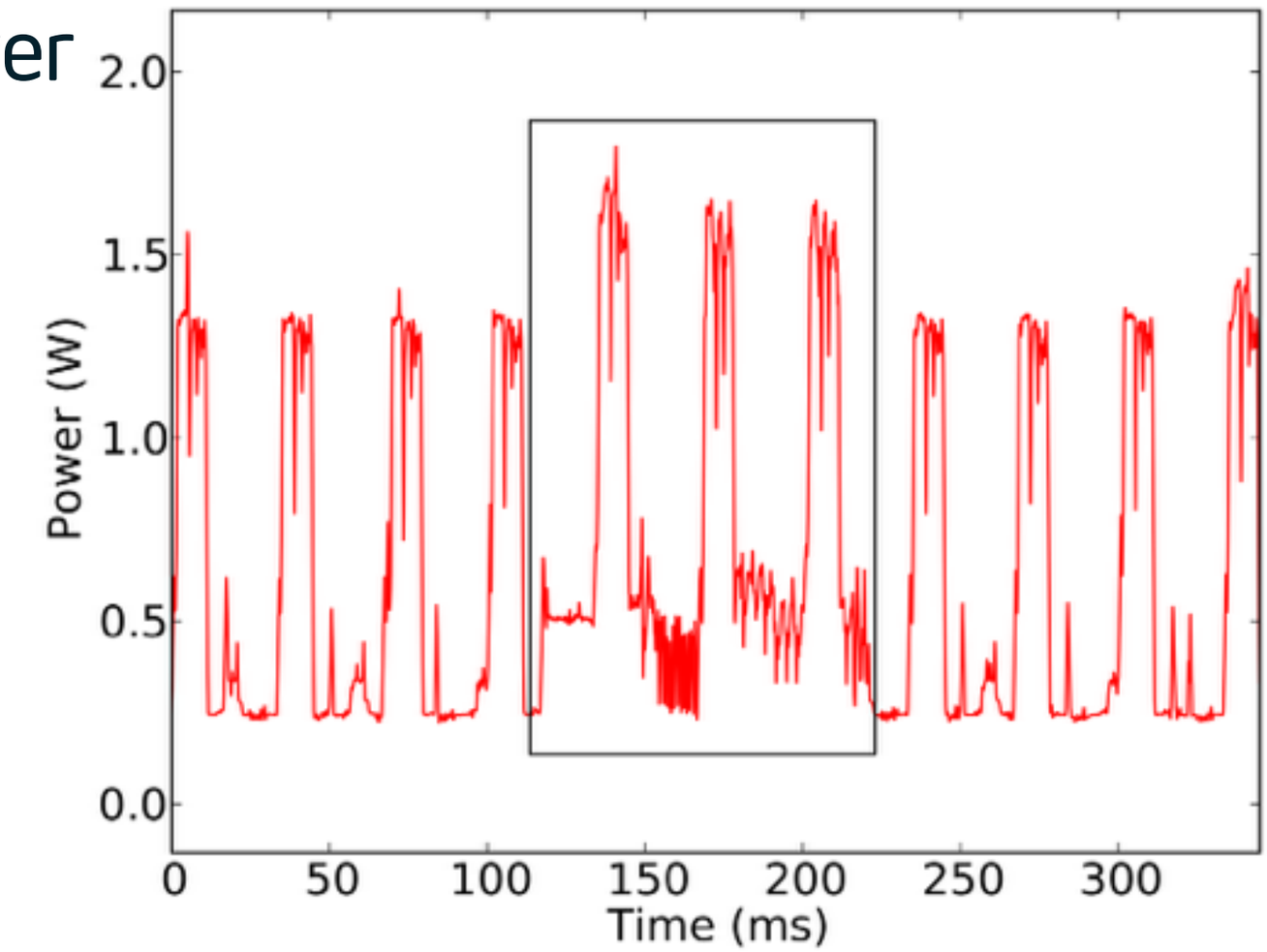
Observations

Disturbance by Operating System

- Few frames with higher power
- 90ms every 5s
  - Same pattern without app running

Similar disturbances on most platforms

- Mostly irregular
  - E.g. on integrated GPUs



iPhone 4S

Conclusions

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Method recap

Conclusions

Method recap

Three steps

Conclusions

Method recap

Three steps

- Measure current and voltage

Conclusions

Method recap

Three steps

- Measure current and voltage
- Record or detect frame starts

Conclusions

Method recap

Three steps

- Measure current and voltage
- Record or detect frame starts
- Integrate power to get energy per frame

Conclusions

Our advice

Conclusions

Our advice

- Avoid changing the workload

Conclusions

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- Disregard the first few seconds after launch

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- Avoid changing the workload
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Get to know your platform!

Conclusions

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Get to know your platform!

Measure

Conclusions

Our advice

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Get to know your platform!

Measure **Observe**

Conclusions

Our advice

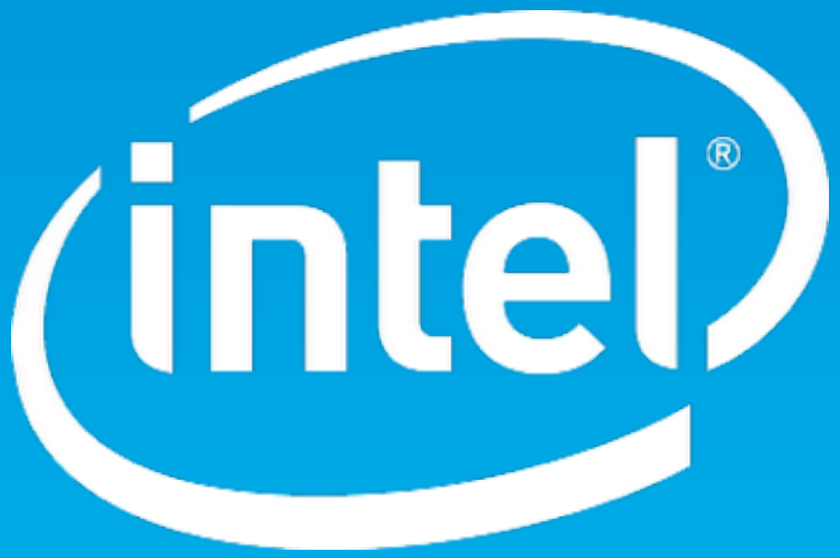
- Avoid changing the workload
- Disregard the first few seconds after launch
- Be aware of the operating system

Get to know your platform!

Measure **Observe**

Find the pitfalls of your platform

Thank You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