EPFL Center for Imaging

Basics of GPU Acceleration for Image Processing

Imaging Lunch

Joan Rué Queralt — 17/04/24

Preview

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What we will see today

- CPU Architecture
- GPU Architecture
- GPU Execution Model
- CUDA programming with Python: Numba, CuPy and cuCIM

What we won't see today

- GPU Memory (hierarchy, shared memory, unified memory)
- Multi-GPU
- DL / ML
- AMD / Intel GPUs & OpenCL
- Other CUDA Python Libraries: PyCUDA, PyTorch, TensorFlow, scikit-cuda, ...

Poll

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The Evolution of GPUs

Major Milestones

Early Graphics Hardware

Integrated Graphics Processors

The Dawn of GPUs

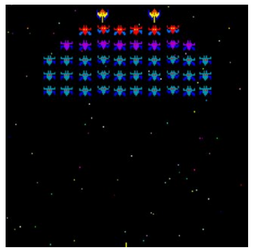
Programmable Shading and Multi-GPU Setups

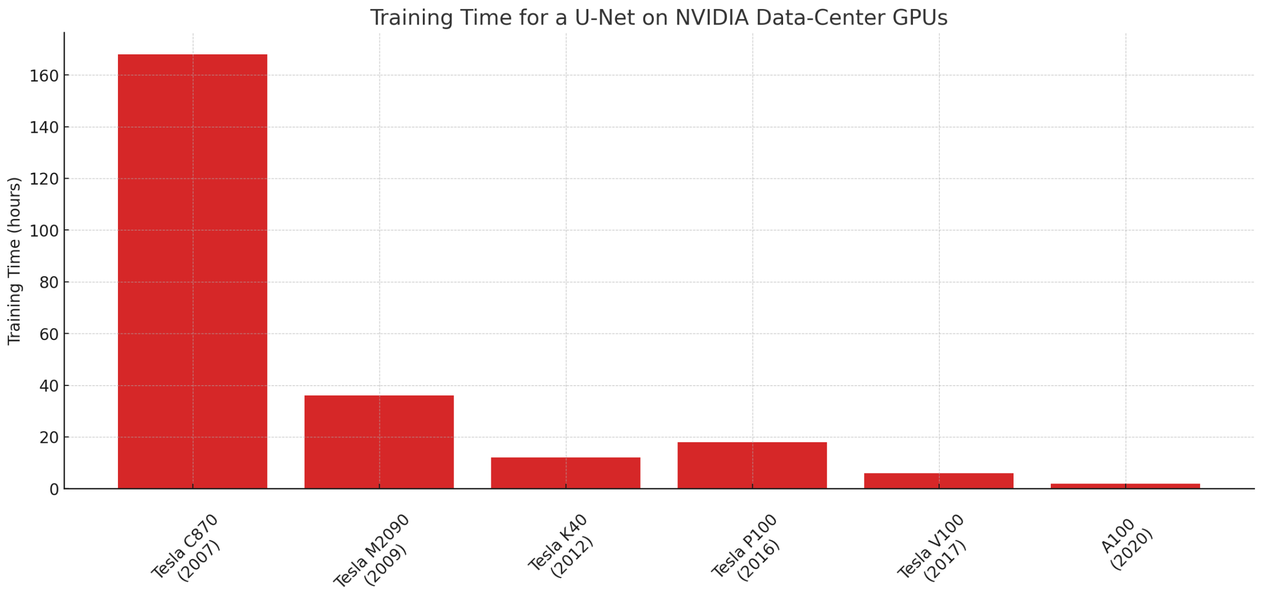
Ray Tracing & AI Acceleration

Advancements in AI & Real-Time Rendering

1970 | 1980 | 1990 | 2000 | 2010 | 2020

2007: NVIDIA launches CUDA

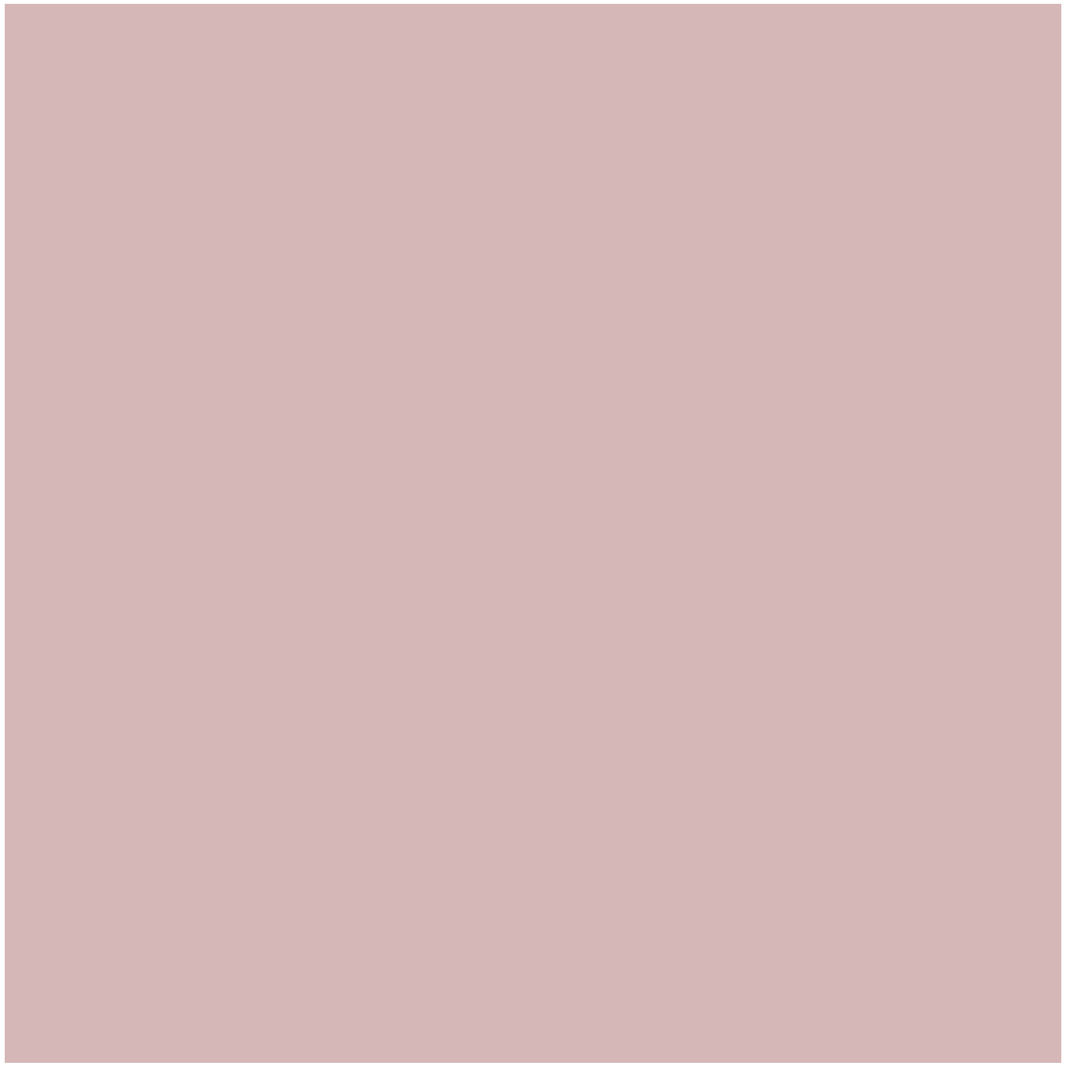




https://shadow.tech/en-GB/blog/history-of-gaming-gpus

CPU chip architecture

- General purpose processor



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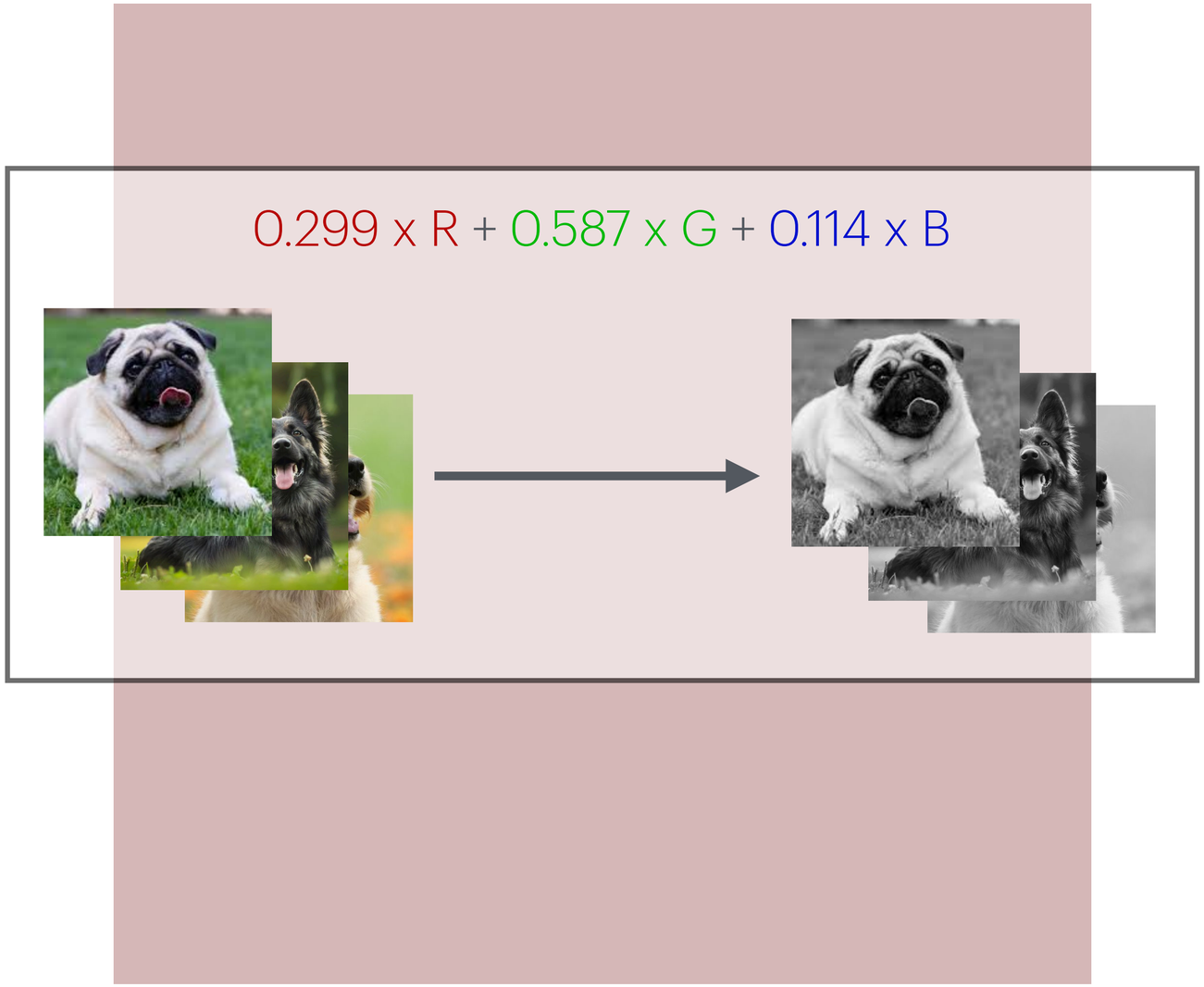

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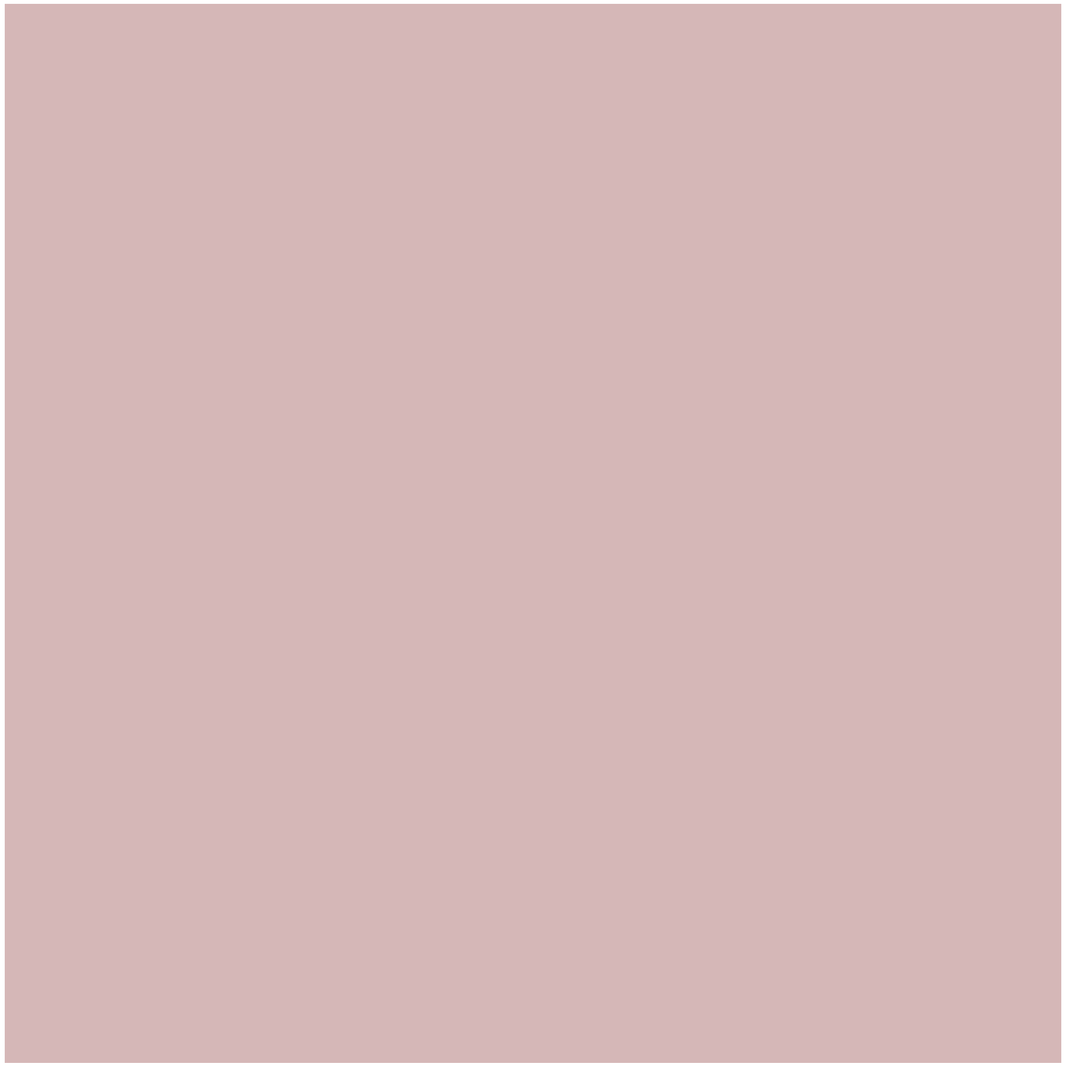
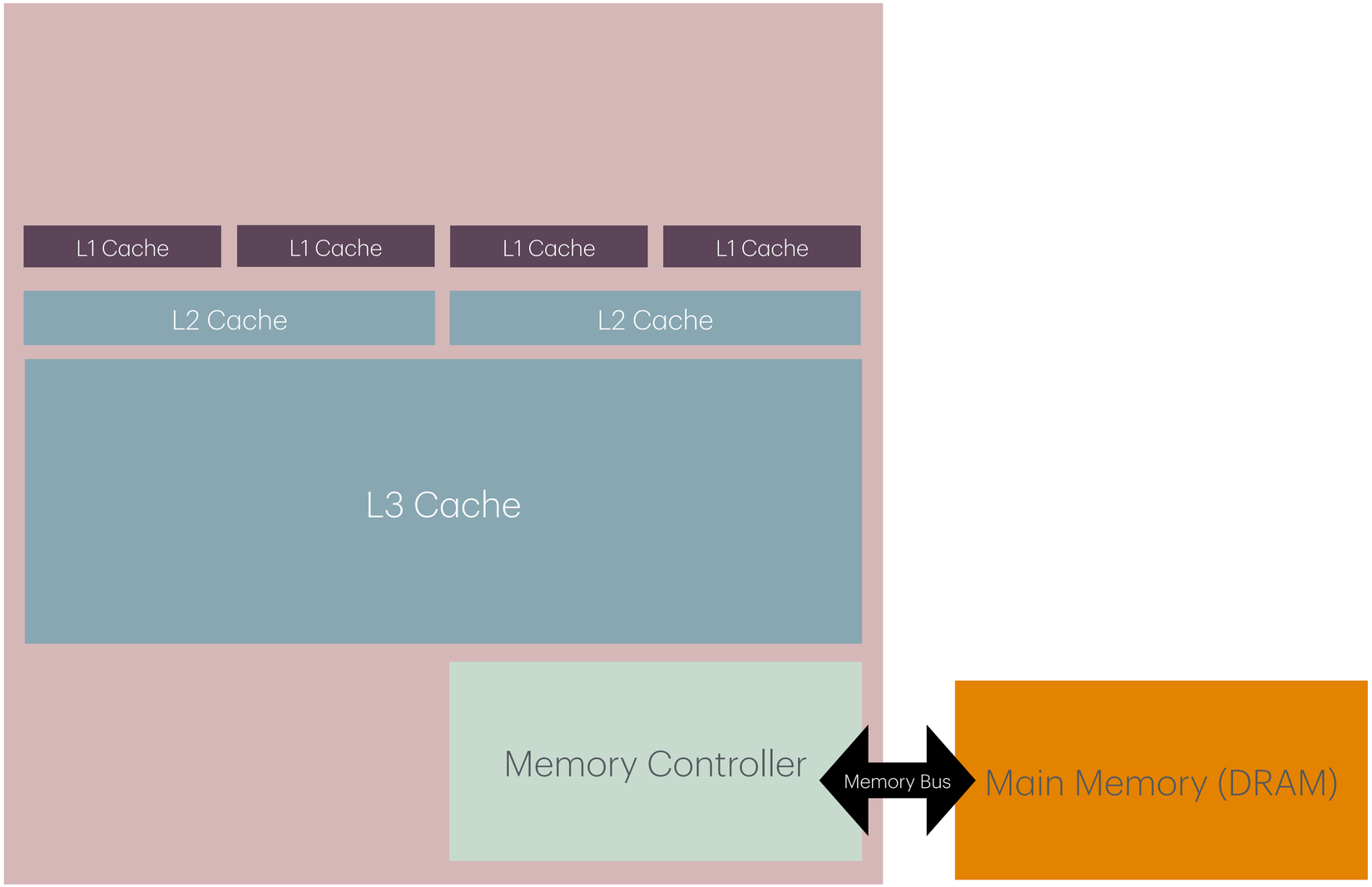


CPU chip architecture

- General purpose processor
- Memory Controller is integrated
- Different Cache Levels
  The lower level the smaller memory and faster access



CPU chip architecture

- General purpose processor
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- Different Cache Levels
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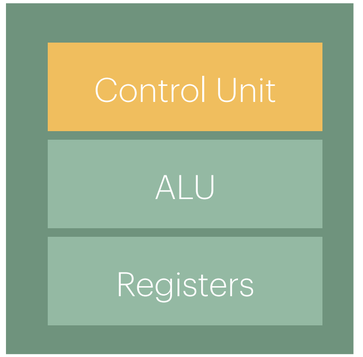
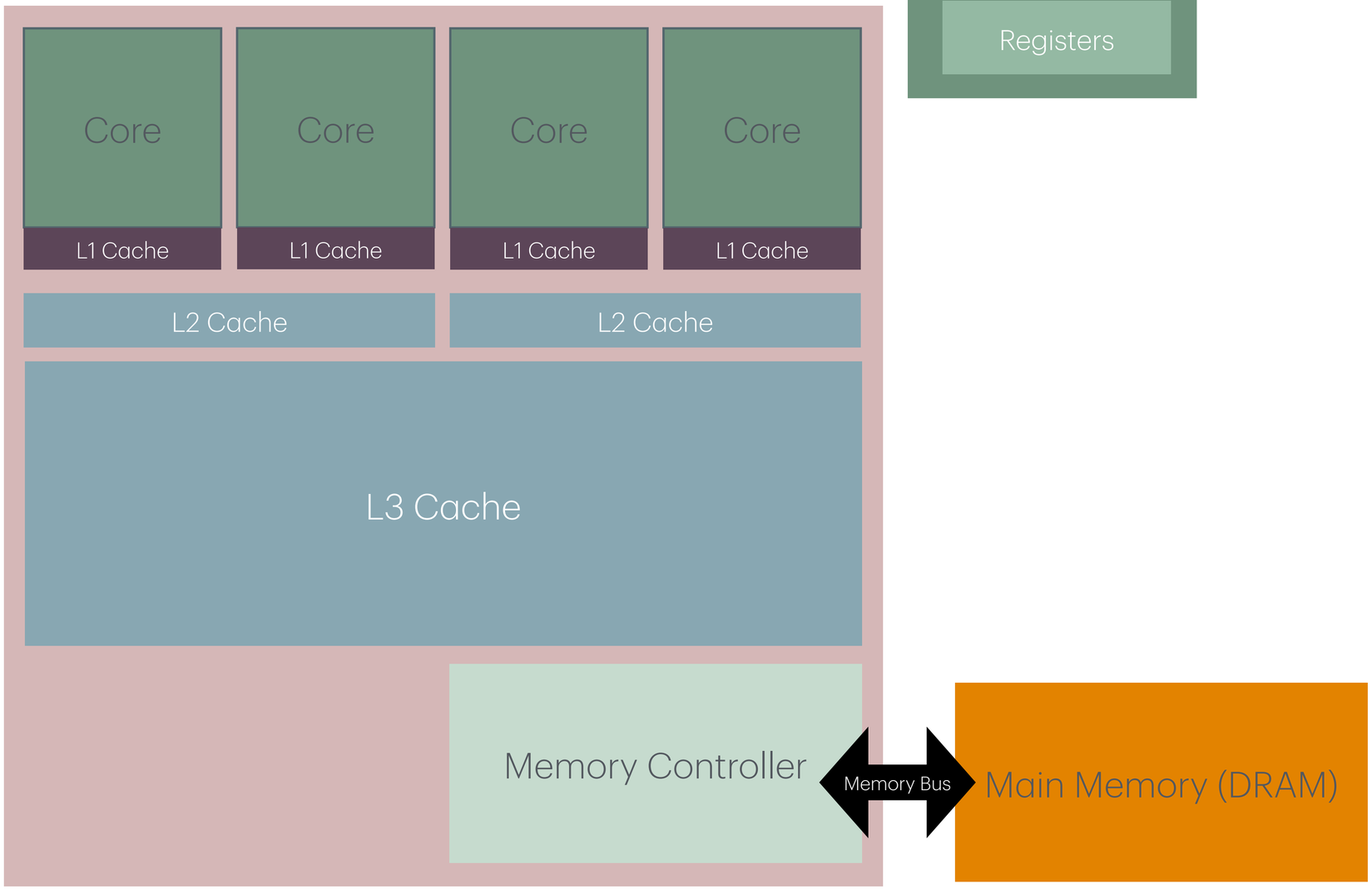
- Between 2-20 Cores
- Each core is capable of executing program instructions independently of the others
- If the software can run in multiple cores, having more cores will result in more instructions run in parallel





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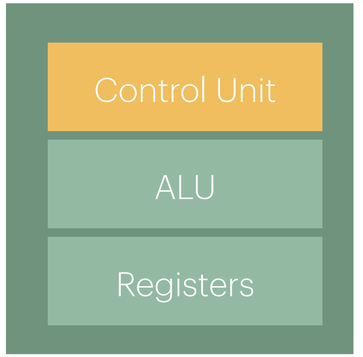

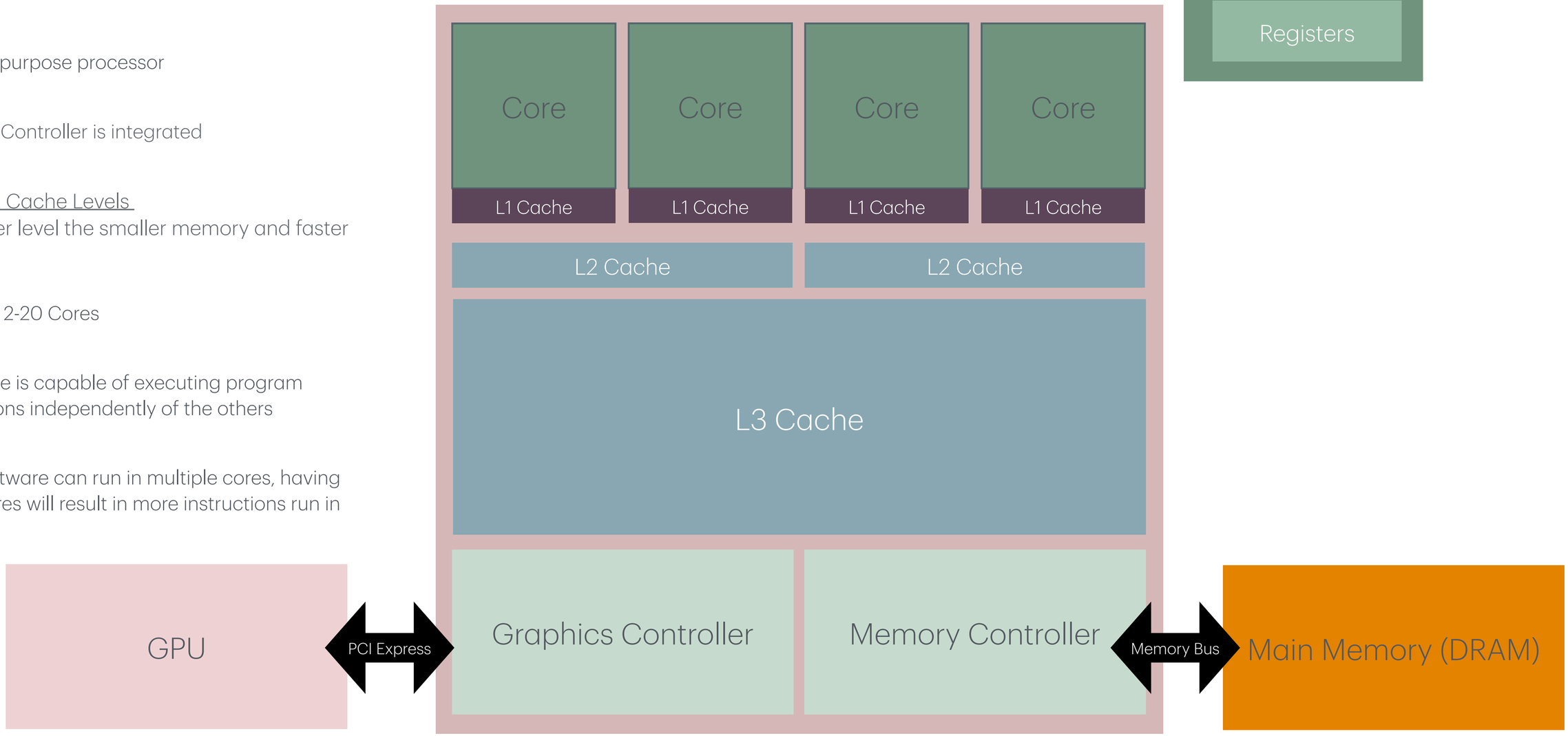

Intel Core i7-3960X

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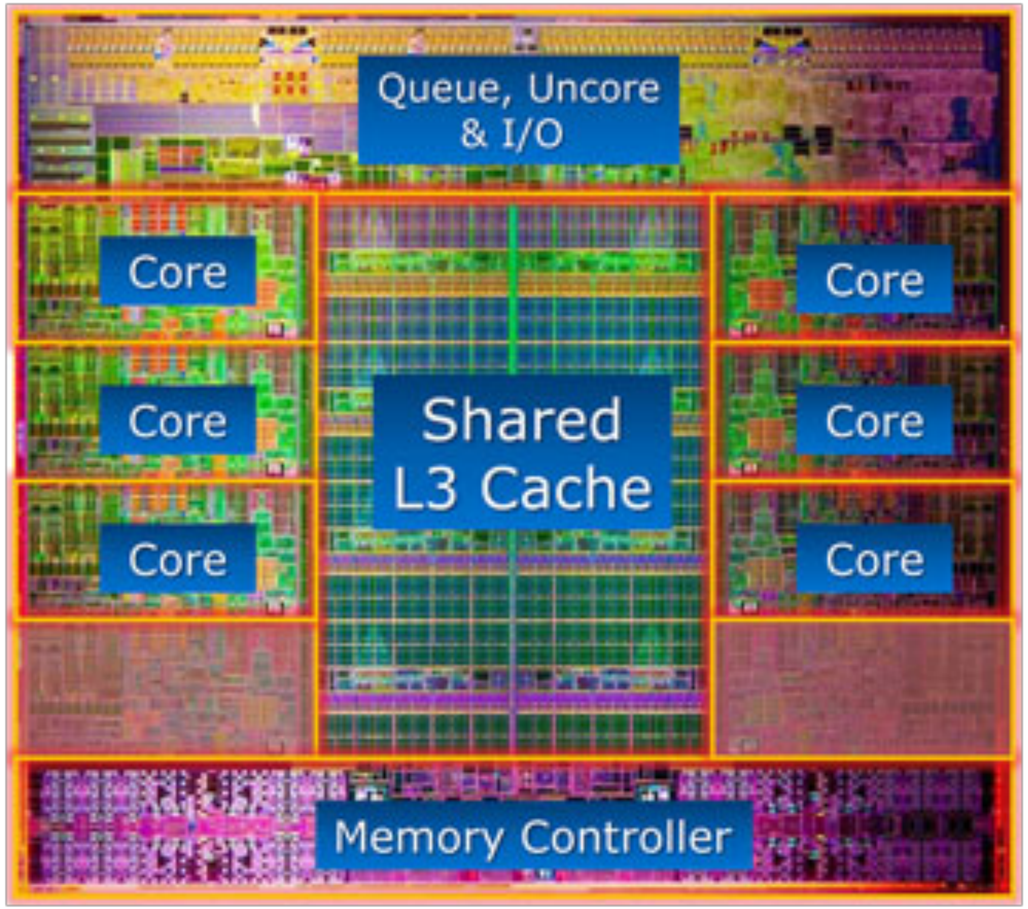
Release year: 2011
6 Cores
HyperThreading (12 threads)
15 MB of L3 cache
Clock speed: 3.3 GHz (boost up to 3.9 GHz)



Graphics card

Circuit board to handle graphics operations

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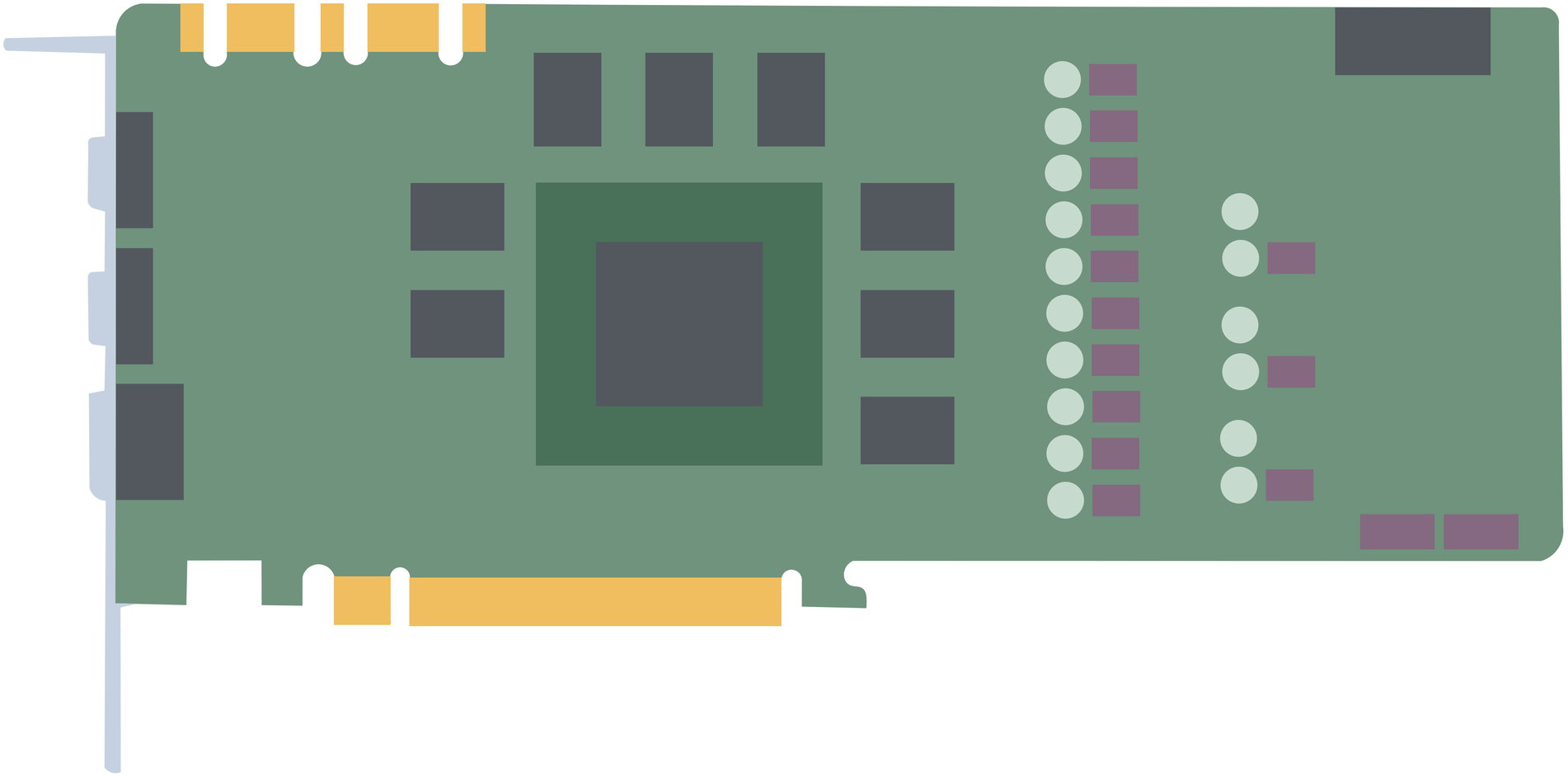
Graphics card

Circuit board to handle graphics operations



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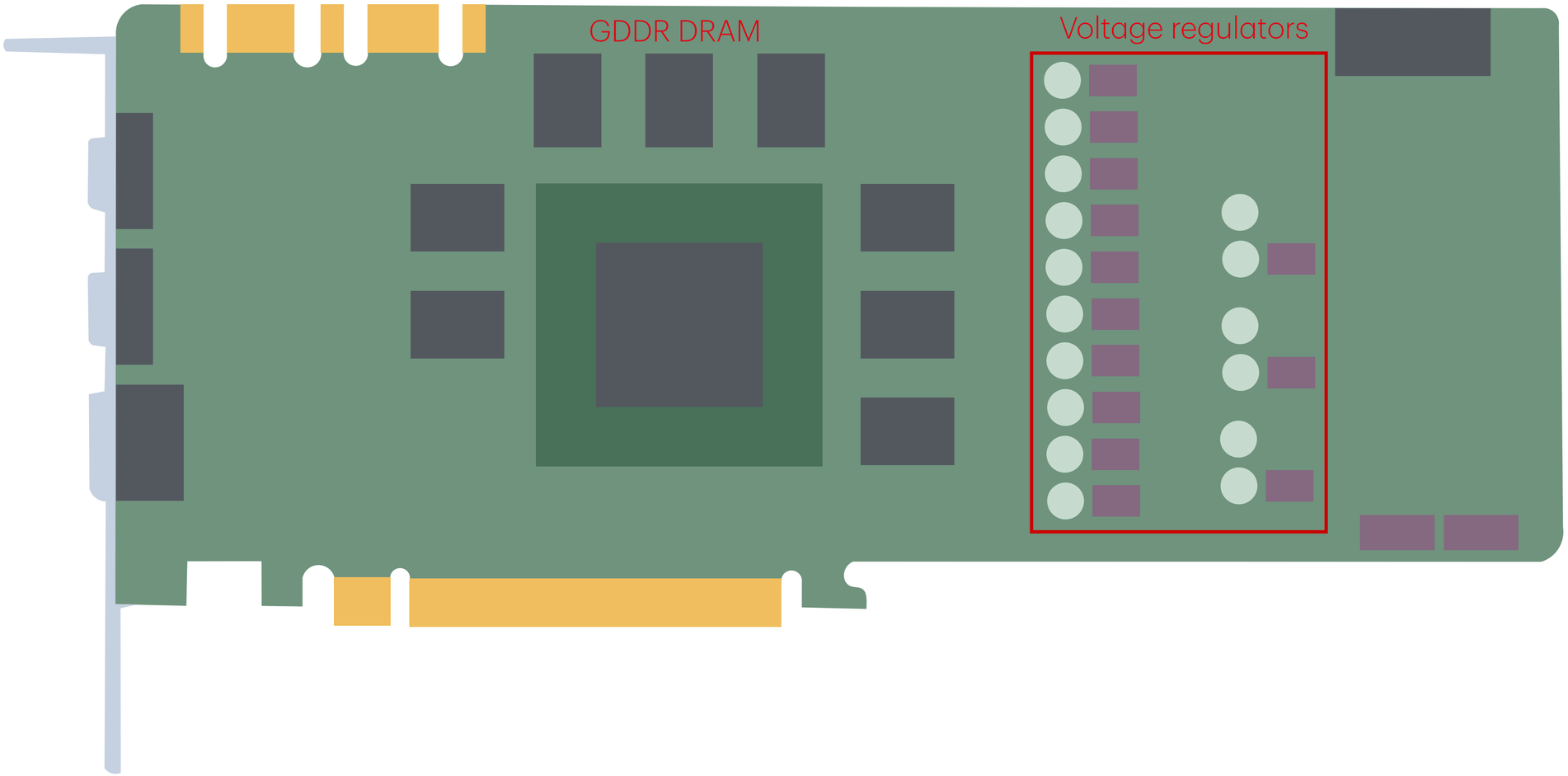

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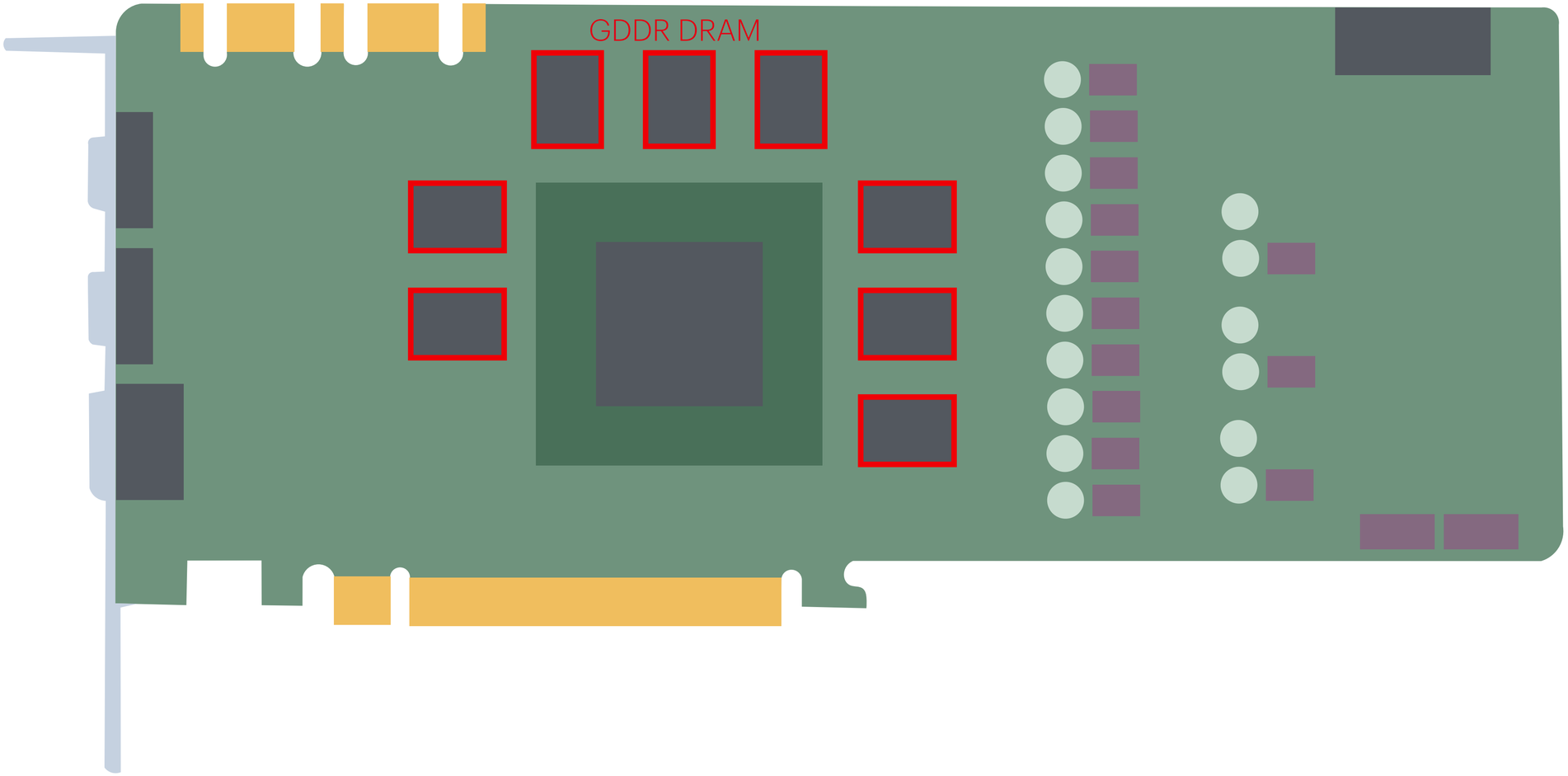

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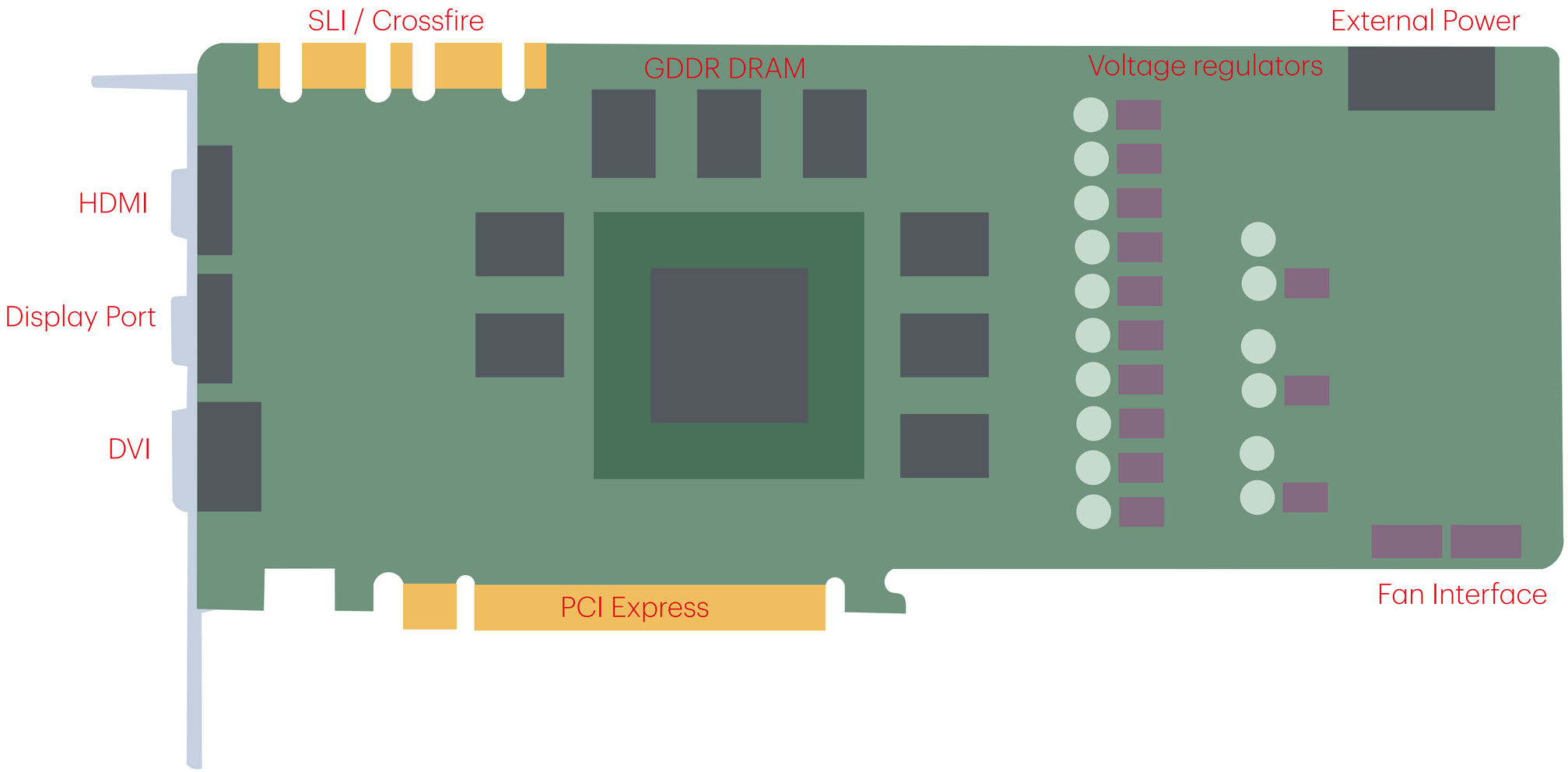

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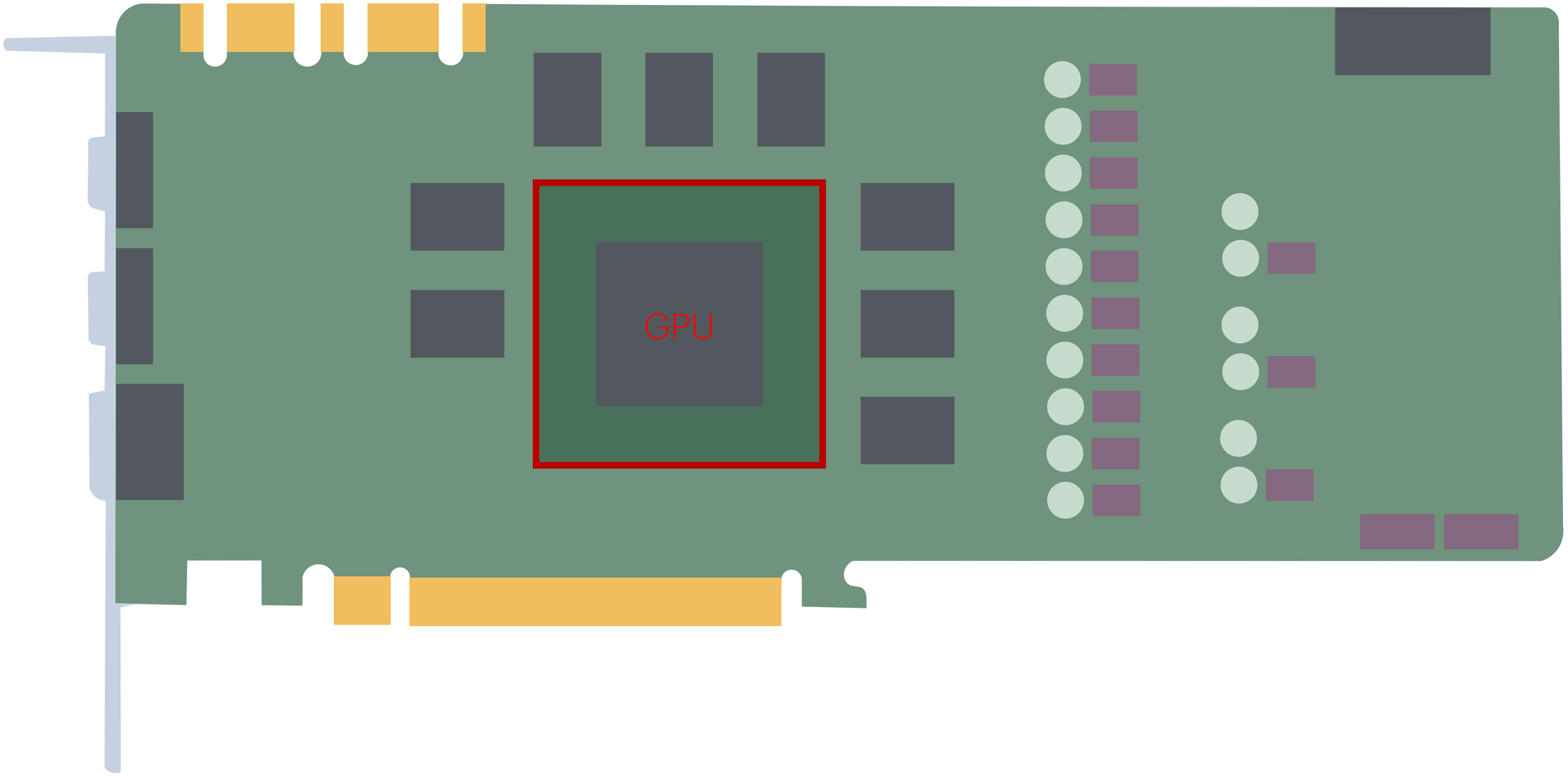

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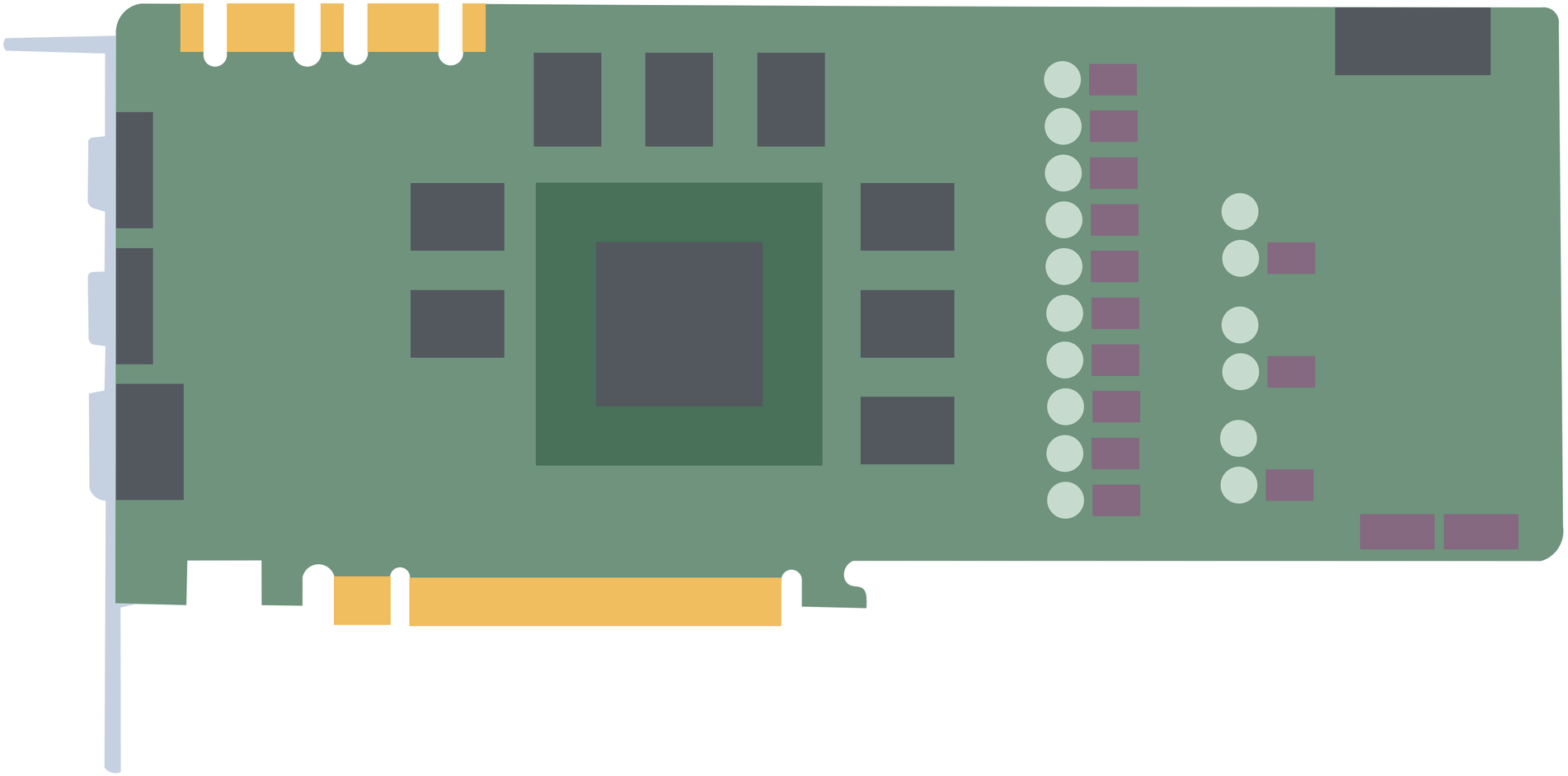

CPU vs GPU

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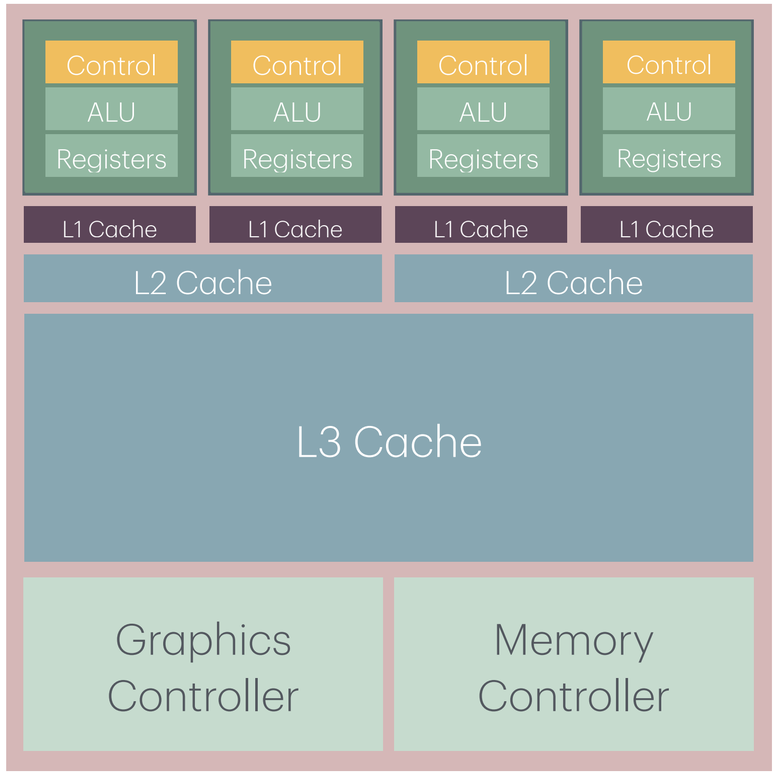
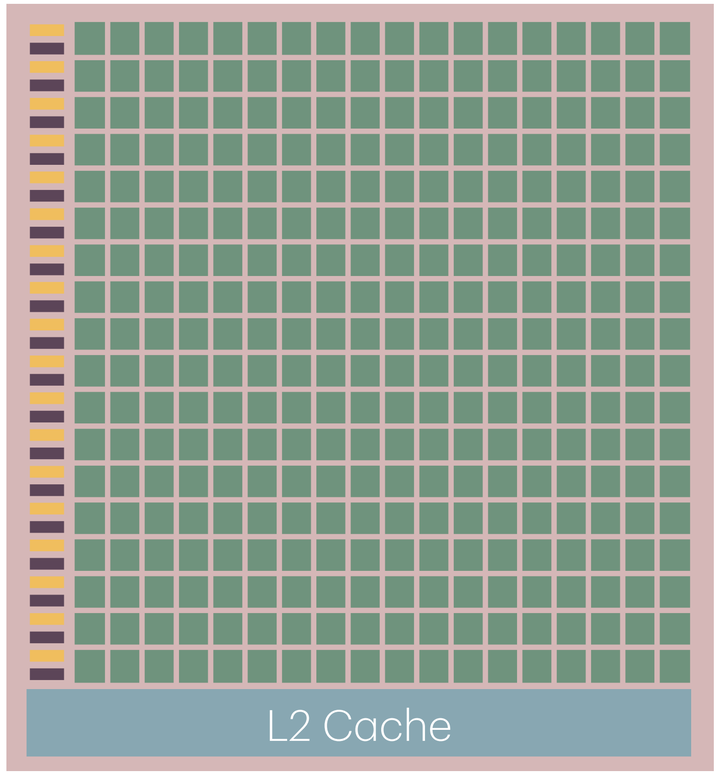
Low-Latency Optimization

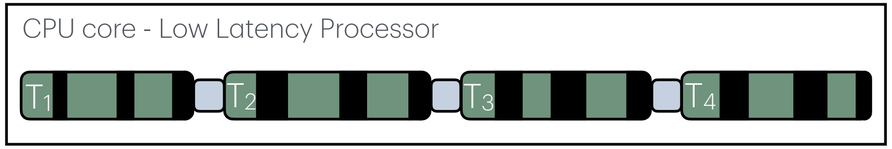
Advanced Control Logic

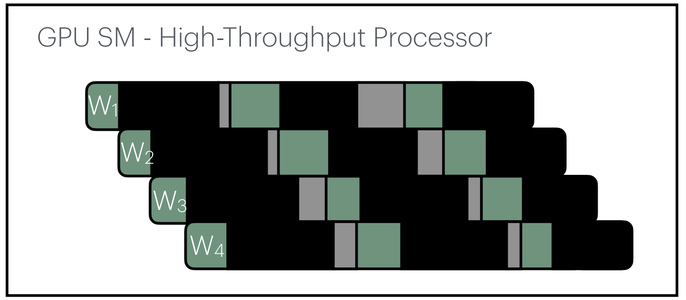


High Throughput

Computation-Heavy Design





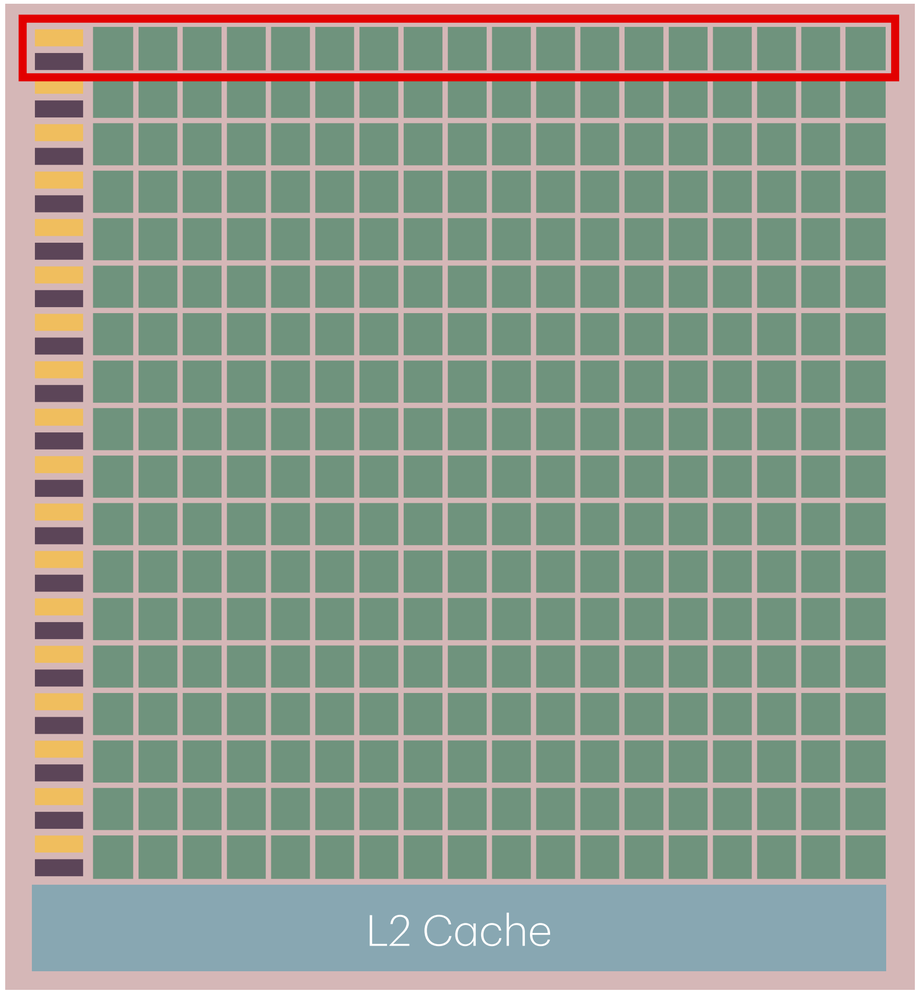


GPU chip architecture

Execution model

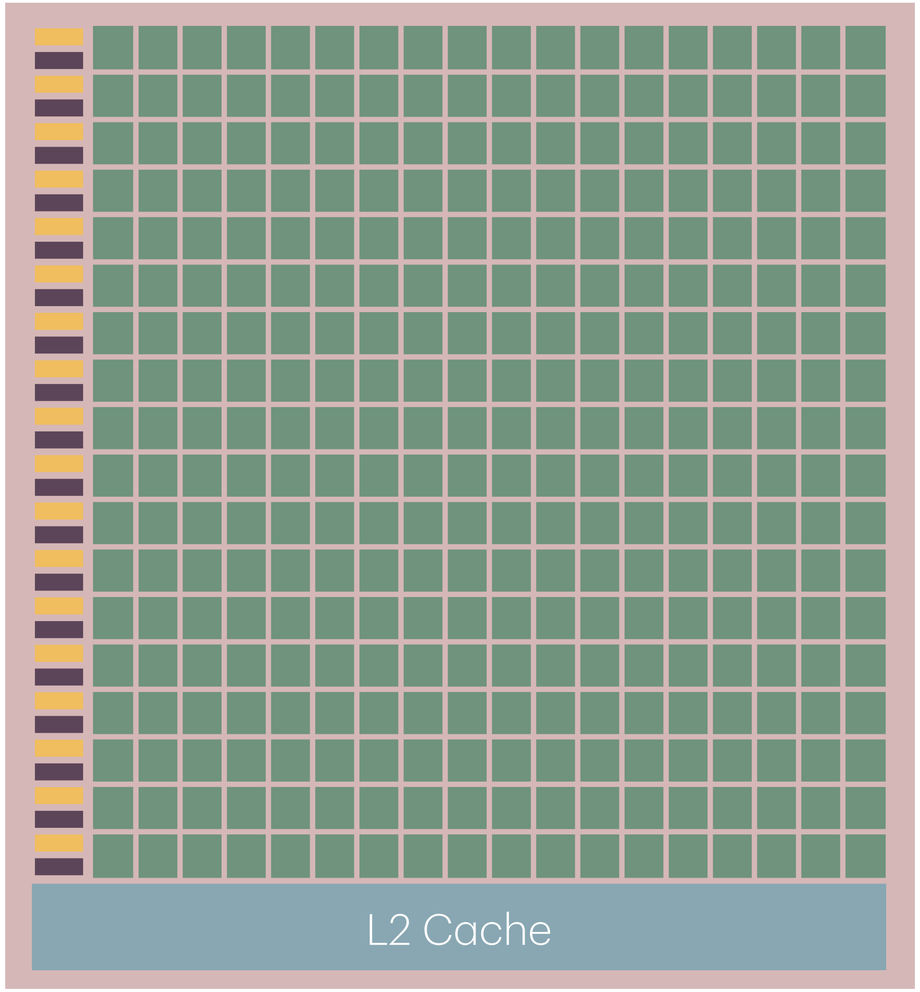
- **Stream processor (SP)**
  Equivalent to a CPU core. Designed to perform few operations but very quickly.

- **Stream Multiprocessor (SM)**
  A cluster of cores sharing a control unit and local memory (L1)
  (Single Instruction Multiple Data, SIMD paradigm)



GPU chip architecture

Execution Hierarchy



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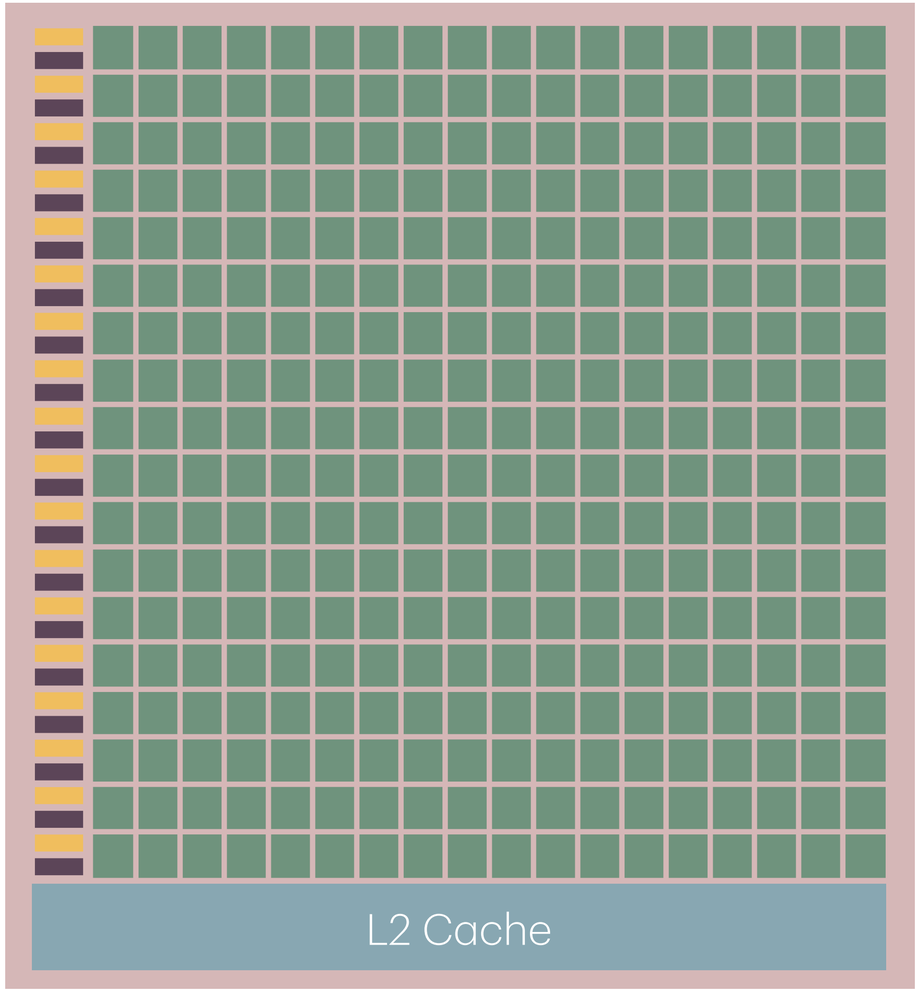
GPU chip architecture

Execution Hierarchy

- **Thread** (Gray[i] = 0.299 * R[i] + 0.587 * G[i] + 0.114 * B[i])
  Is the single execution of a kernel in a single piece of data.
  Runs on one CORE
  One CORE can run multiple threads (one after the other).
  Threads do not execute at the same rate.



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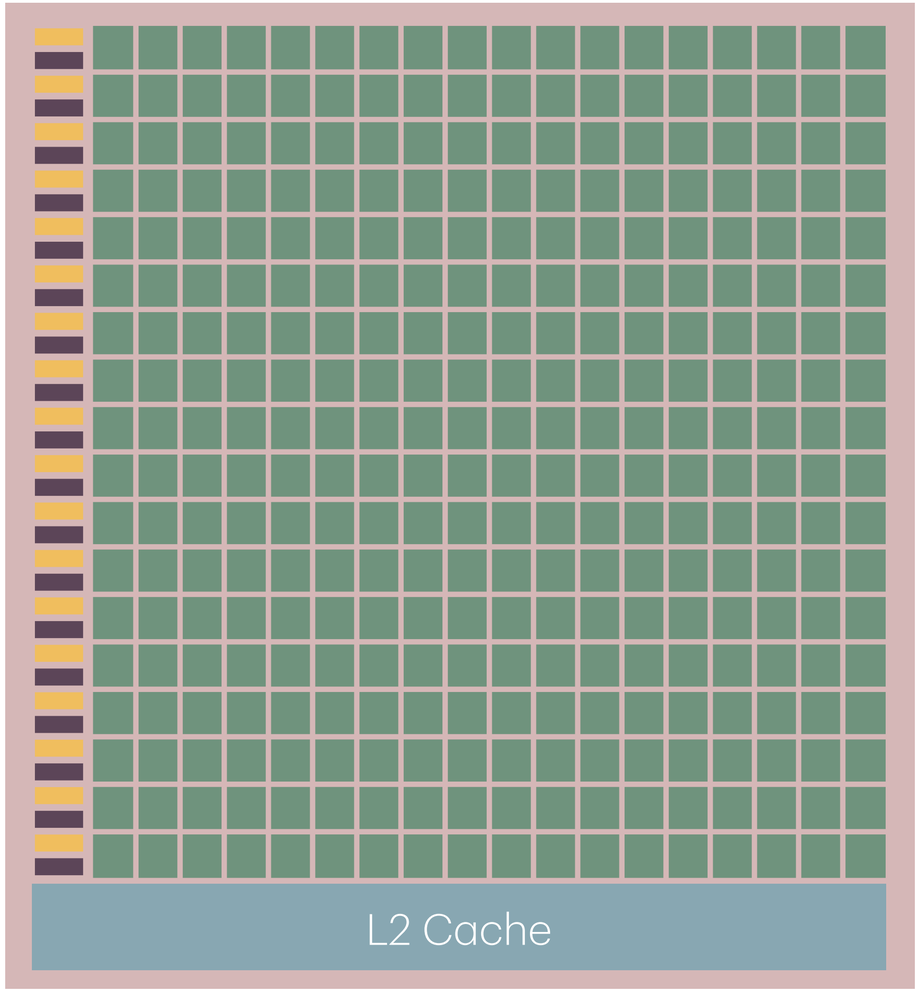
- **Block**: Group of threads that physically share memory.
  Runs on one SM, one SM can run multiple blocks



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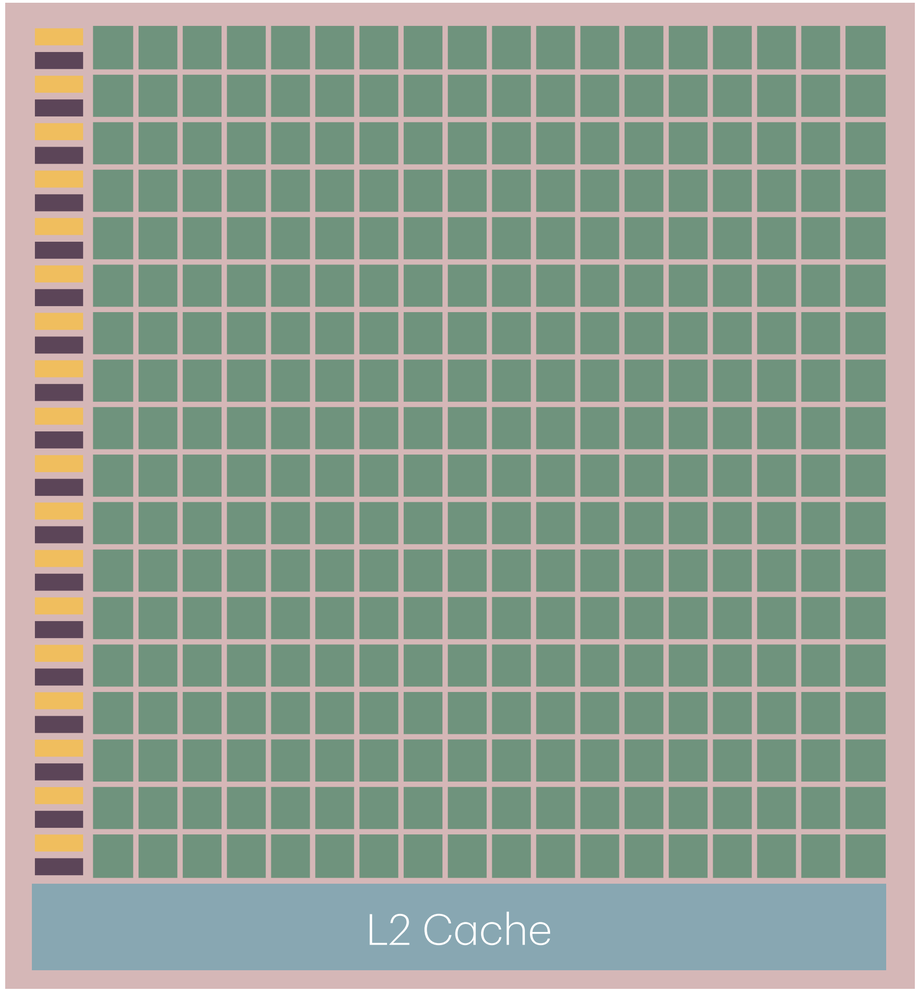
- **Grid**: Group of blocks.



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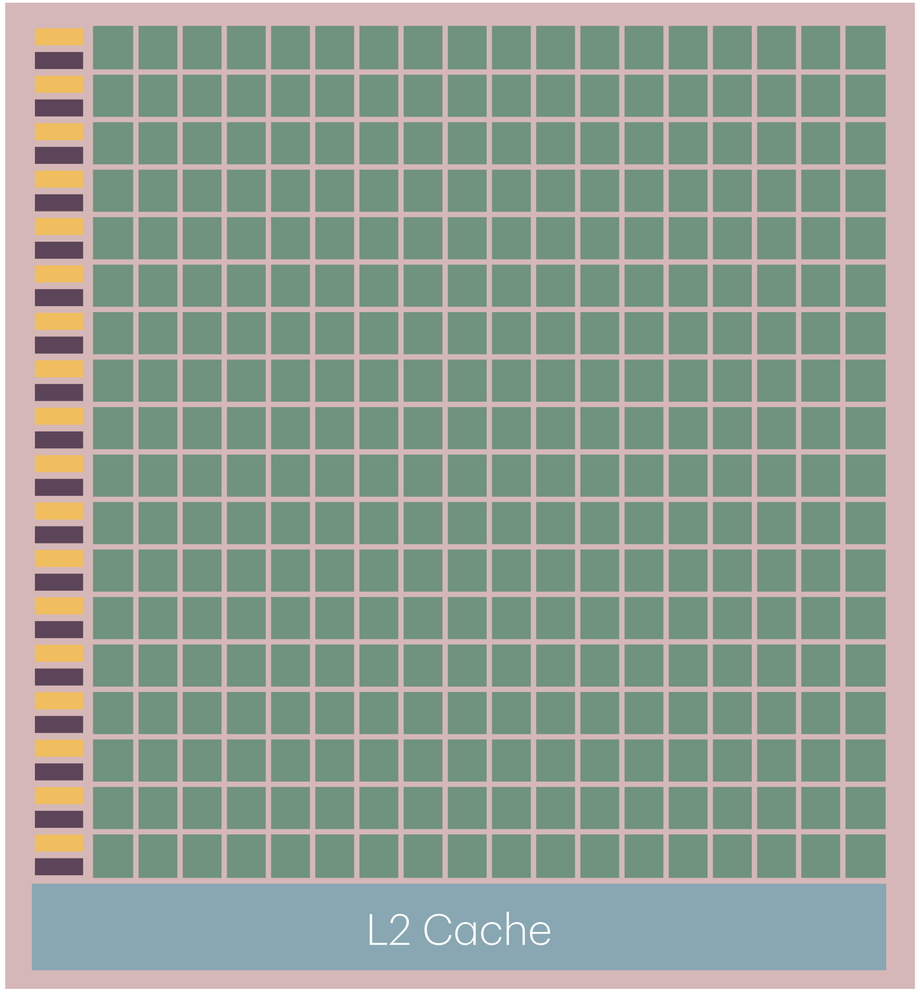
- **Warp**: A fixed number of threads that execute the same instruction at the same time
  (NVIDIA GPUs —> Warp = 32 threads)



Nvidia H100 Full GPU with 144 SMs

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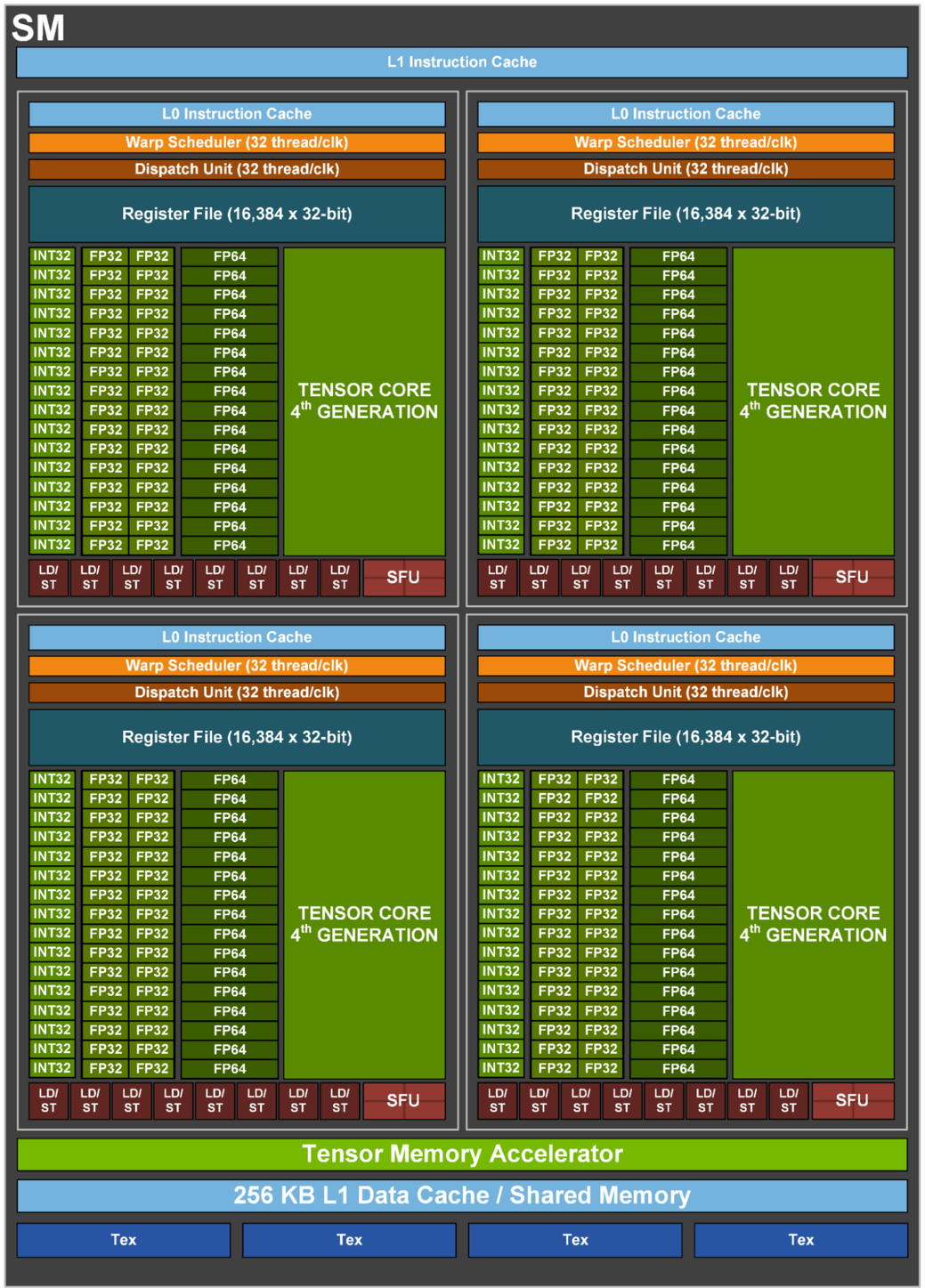
128 FP32 CUDA Cores/SM

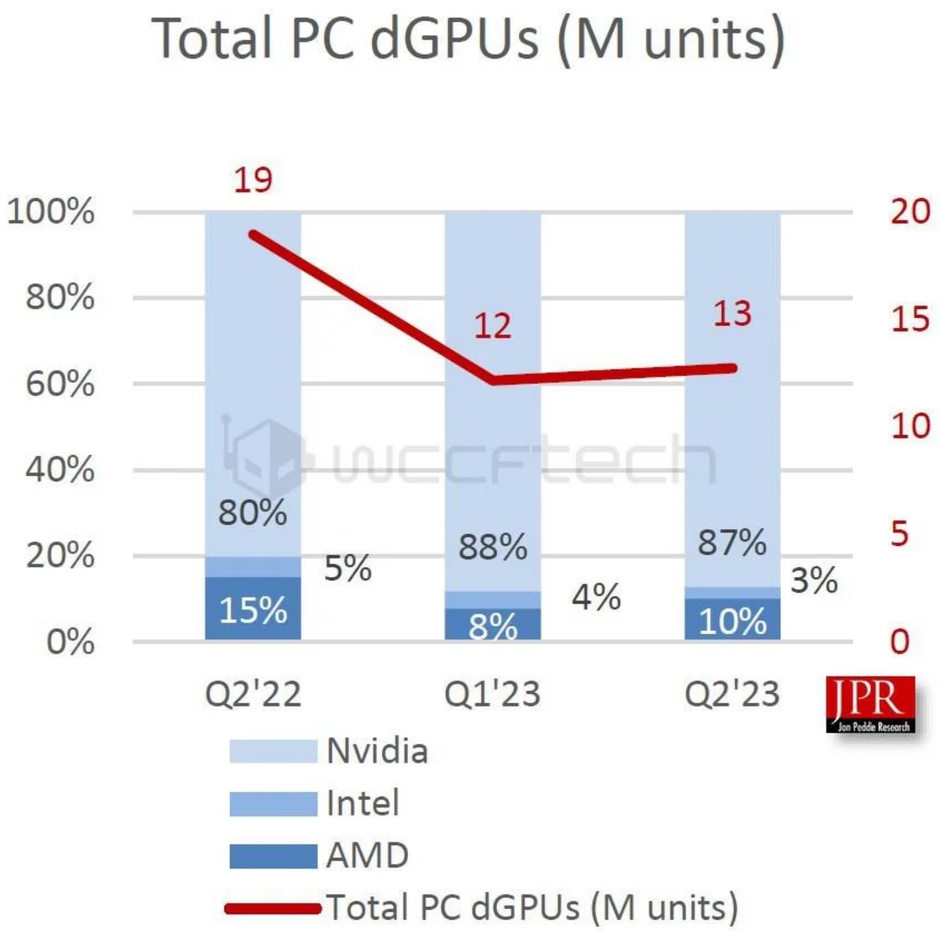
128 Cores/SM
x
144 SM/GPU
=
18,432 Cores/GPU



GPU chip architecture

Execution model

- Host-directed execution
    - CPU sets up and launches instructions on the GPU.
    - CPU manages the memory on the GPU (allocations — transfer in/out)
- Parallelism is needed to cover execution latencies



GPU Marketshare in Q2 2023:

NVIDIA 87%
AMD 10%
Intel 3%.

Desktop dGPUs
NVIDIA 80%
AMD 17%

Laptop dGPUs
NVIDIA 94%
AMD 3%

CUDA

The Basics

- **C**ompute **U**nified **D**evice **A**rchitecture
- Not a programming language —> API / Library for GPU computing
- Can be used from different programming languages
  (C/C+/Python/Matlab/etc.)
- Only for NVIDIA GPUs
  (AMD & Intel —> OpenCL)
- CUDA Kernel: A function to be executed on GPU (e.g., a c++ function)

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- **CUDA Drivers**: Software components that allow the operating system and applications to access and use the hardware capabilities of NVIDIA GPUs.
- **CUDA Toolkit**: A suite of compilers (nvcc), libraries (cuFFT, cuDNN), APIs (CUDA Runtime), and debuggers/profilers essential for building CUDA applications.

https://docs.nvidia.com/cuda/cuda-installation-guide-linux/index.html

Python Libraries

for CUDA Programming

Low-level

PyCUDA (https://documen.tician.de/pycuda/)

Numba (https://numba.readthedocs.io/en/stable/)

CuPy (https://cupy.dev/)

cuCIM (https://docs.rapids.ai/api/cucim/stable/)

High-level

Jupyter notebook

https://github.com/EPFL-Center-for-Imaging/basics-GPU-image-proc

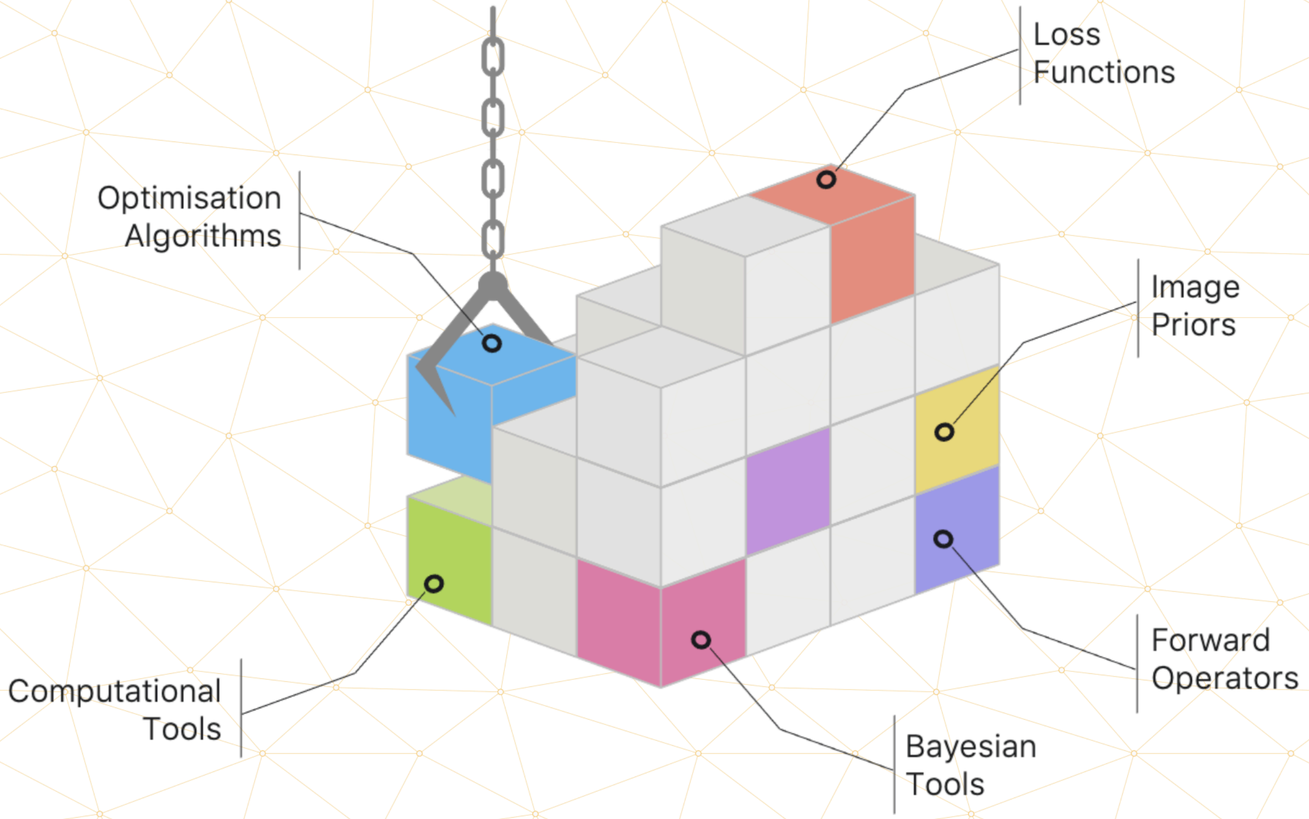
Pyxu

Modular & Scalable Computational Imaging

Pyxu (pronounced [piksu], formerly known as Pycsou) is an open-source Python framework allowing scientists at any level to quickly prototype/deploy *hardware accelerated and out-of-core* computational imaging pipelines at scale. Thanks to its hardware-agnostic **microservice architecture** and its tight integration with the PyData ecosystem, Pyxu supports a wide range of imaging applications, scales, and computation architectures.

Get Started | See Examples

See API Reference →



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