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Unified Memory

Notes on GPU Data Transfers

Andreas Herten, Forschungszentrum Jülich, 24 April 2017 *Handout Version*

Overview, Outline

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Overview

- Unified Memory enables easy access to GPU development
- But some tuning might be needed for best performance

Contents

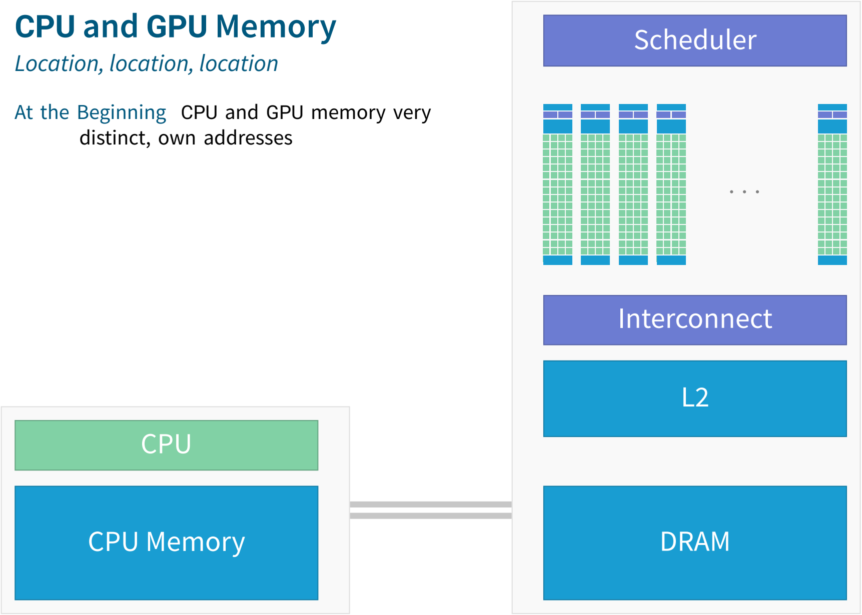
Background on Unified Memory

History of GPU Memory

CPU and GPU Memory

Location, location, location

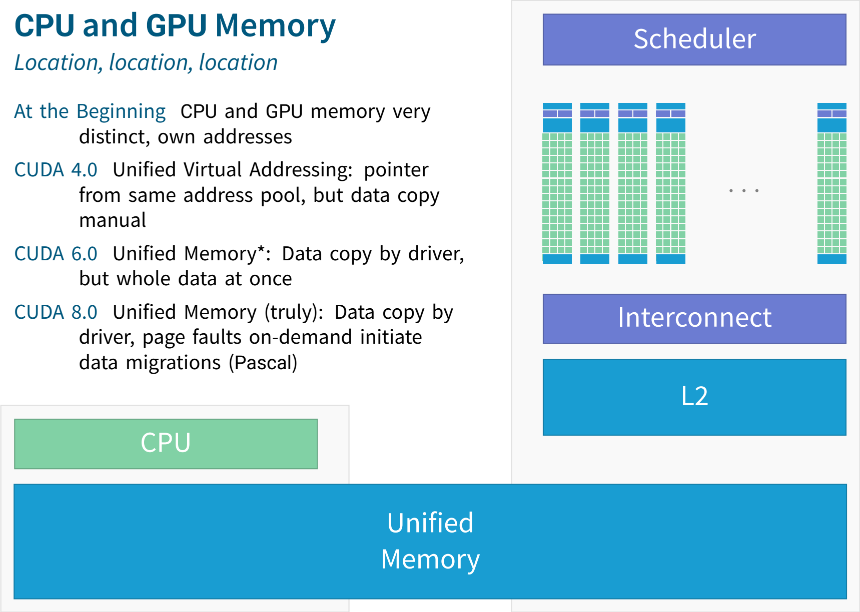
At the Beginning CPU and GPU memory very distinct, own addresses



CPU and GPU Memory

Location, location, location

- At the Beginning: CPU and GPU memory very distinct, own addresses
- CUDA 4.0: Unified Virtual Addressing: pointer from same address pool, but data copy manual
- CUDA 6.0: Unified Memory*: Data copy by driver, but whole data at once
- CUDA 8.0: Unified Memory (truly): Data copy by driver, page faults on-demand initiate data migrations (Pascal)



Unified Memory in Code

Vojgjfe Nfnpsz

```
void sortfile(FILE *fp, int N) {
    char *data;
    char *data_d;

    data = (char *)malloc(N);
    cudaMalloc(&data_d, N);

    fread(data, 1, N, fp);

    cudaMemcpy(data_d, data, N,
    ↪   cudaMemcpyHostToDevice);
    kernel<<<...>>>(data, N);

    cudaMemcpy(data, data_d, N,
    ↪   cudaMemcpyDeviceToHost);
    host_func(data);
    cudaFree(data_d); free(data); }
```

```
void sortfile(FILE *fp, int N) {
    char *data;

    cudaMallocManaged(&data, N);

    fread(data, 1, N, fp);

    kernel<<<...>>>(data, N);
    cudaDeviceSynchronize();

    host_func(data);
    cudaFree(data); }
```

Implementation Details (on Pascal)

Under the hood

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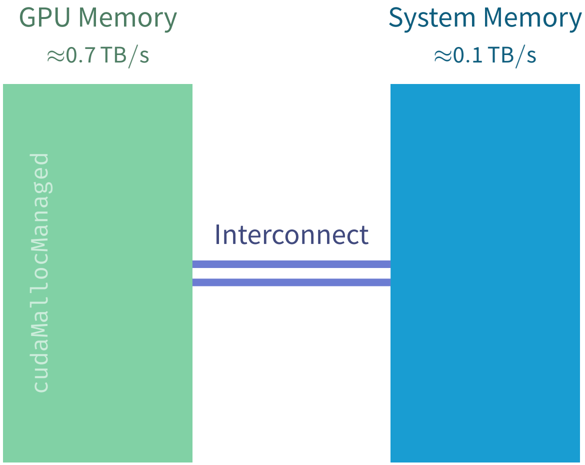
`cudaMallocManaged(&ptr, ...);`	Empty! No pages anywhere yet (like `malloc()`)
`*ptr = 1;`	CPU page fault: data allocates on CPU
`kernel<<<...>>>(ptr);`	GPU page fault: data migrates to GPU

- Pages populate on **first touch**
- Pages migrate on-demand
- GPU memory over-subscription possible
- Concurrent access from CPU and GPU to memory (page-level)

On-Demand Migration Flow at Pascal



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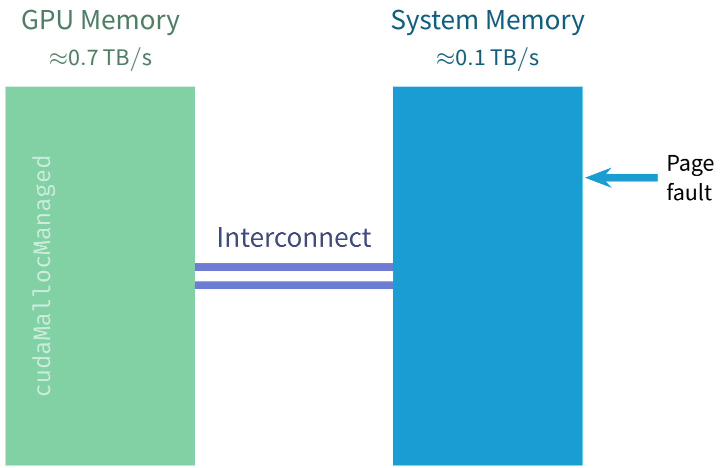

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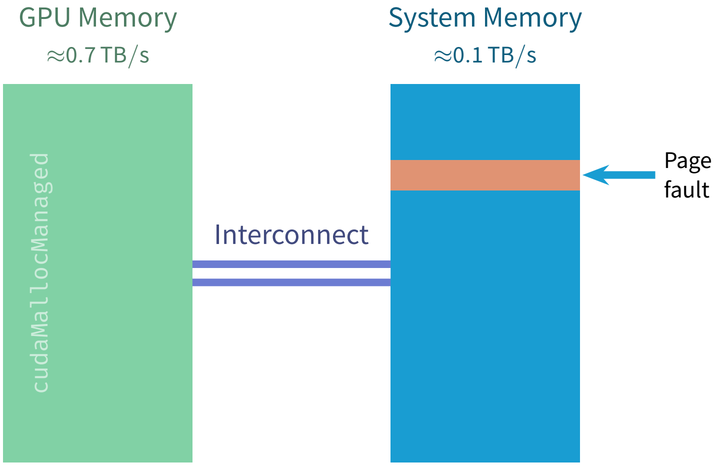

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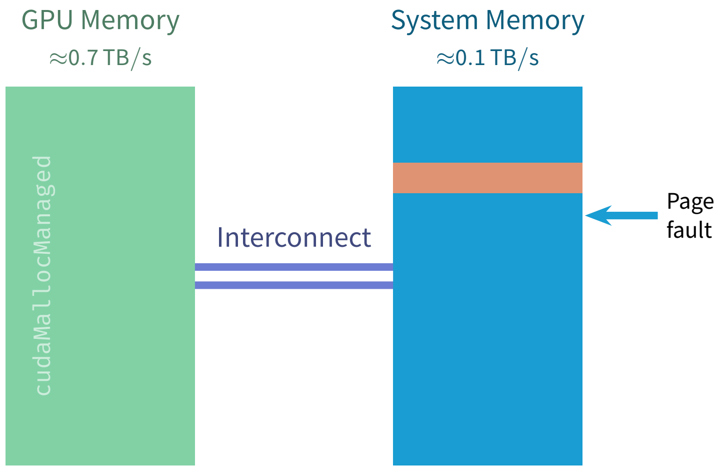

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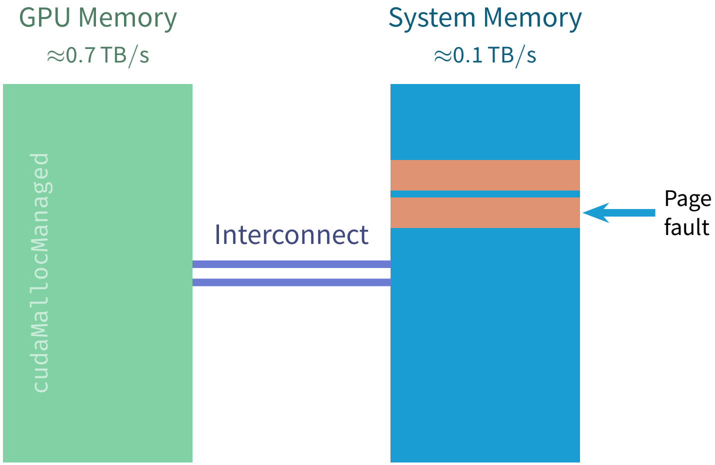

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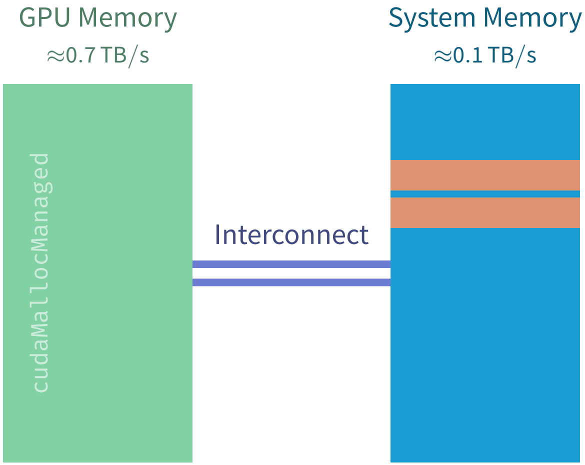

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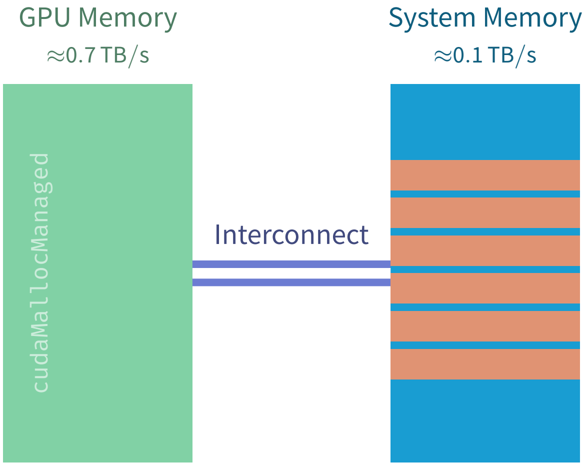

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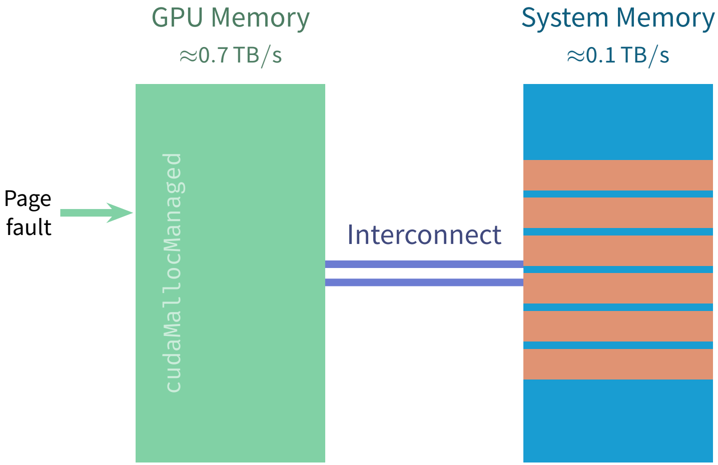

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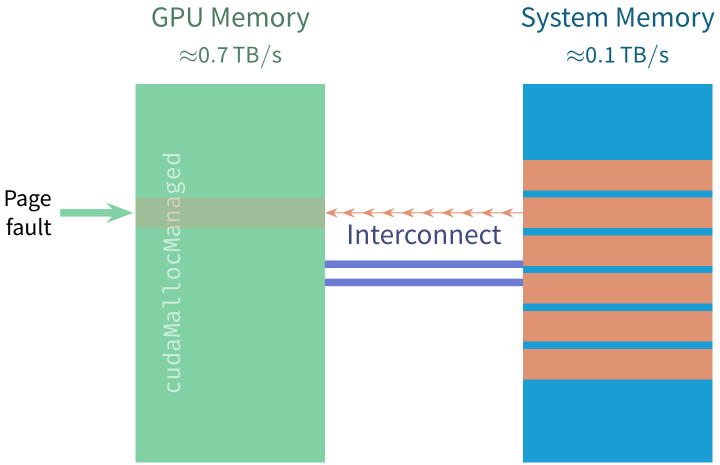

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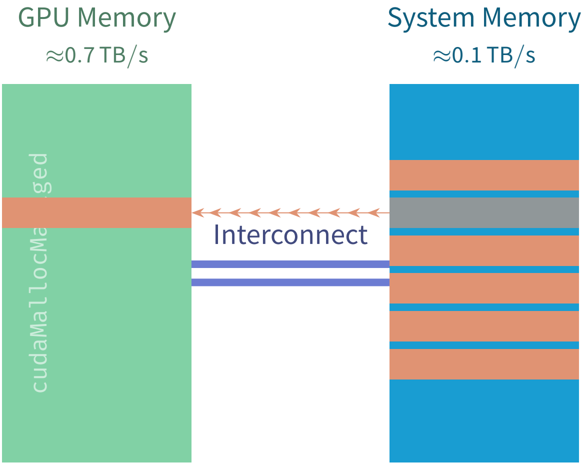

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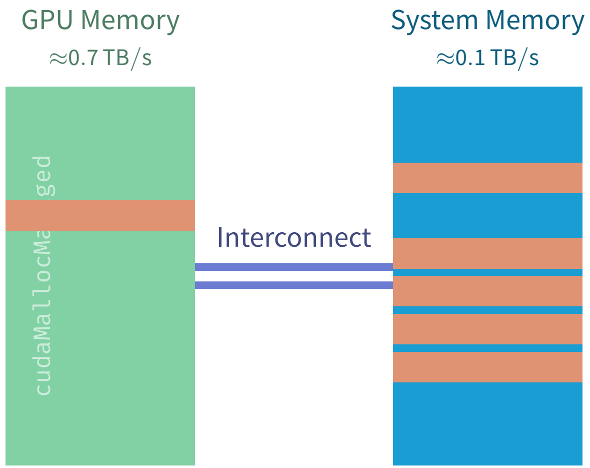

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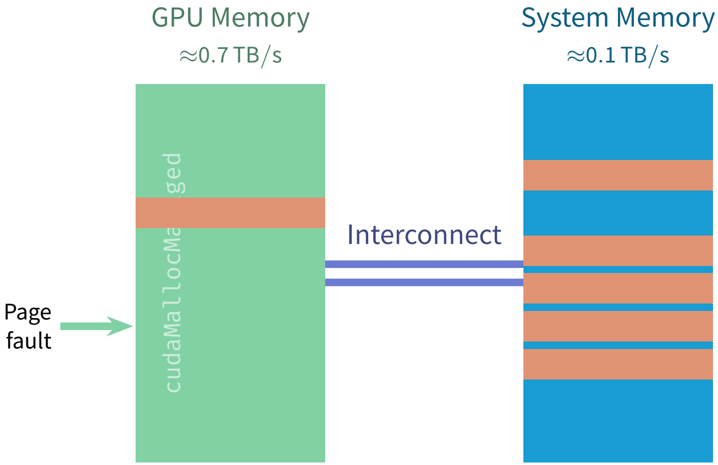

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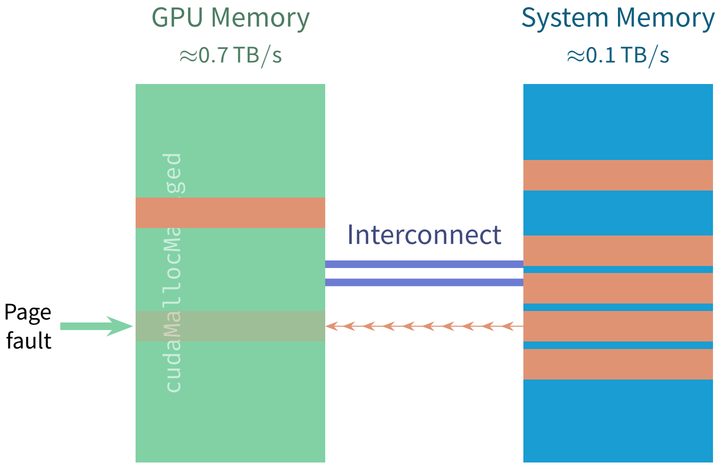

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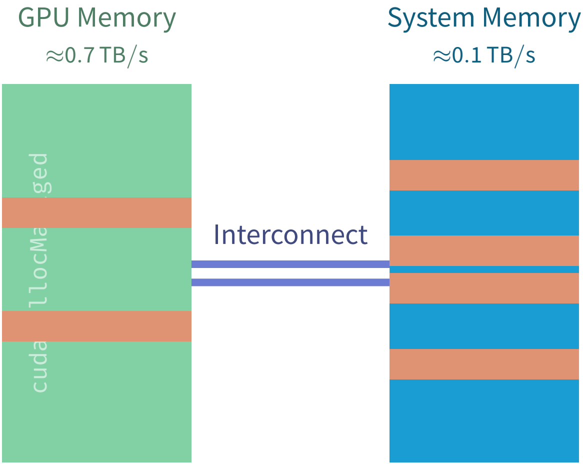

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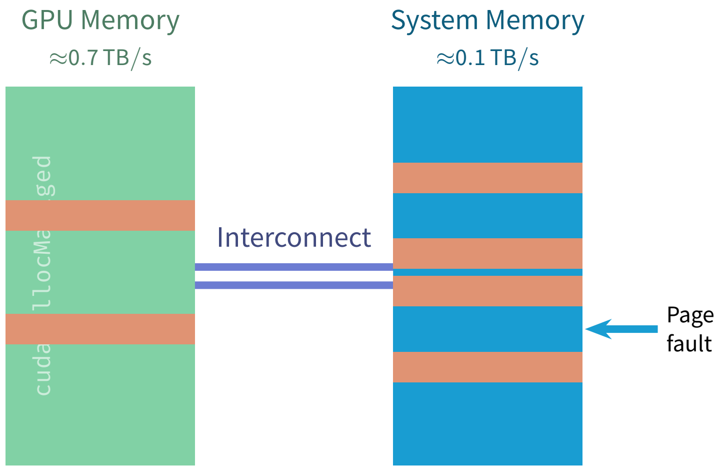

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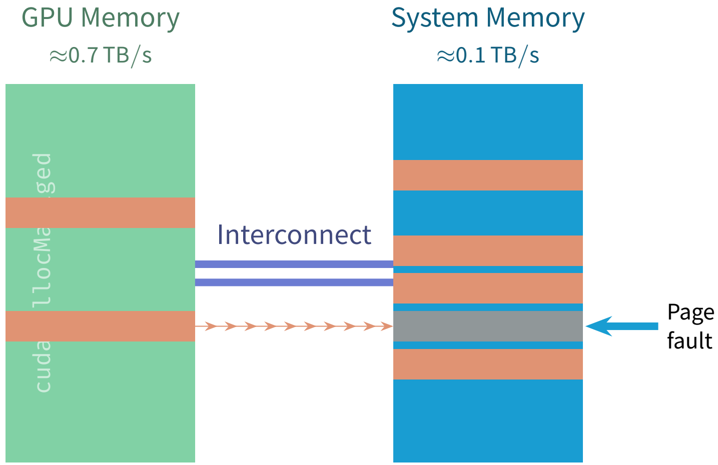

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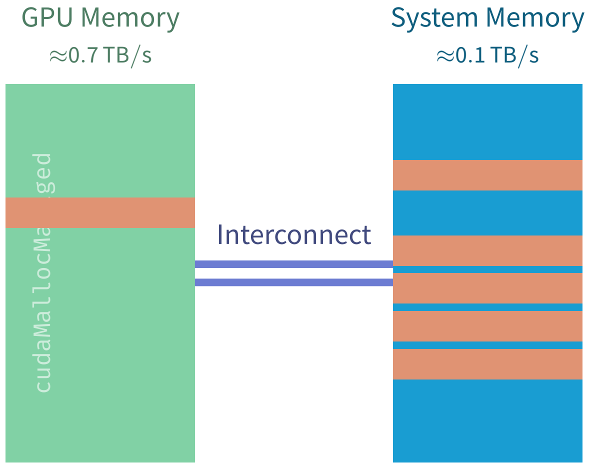

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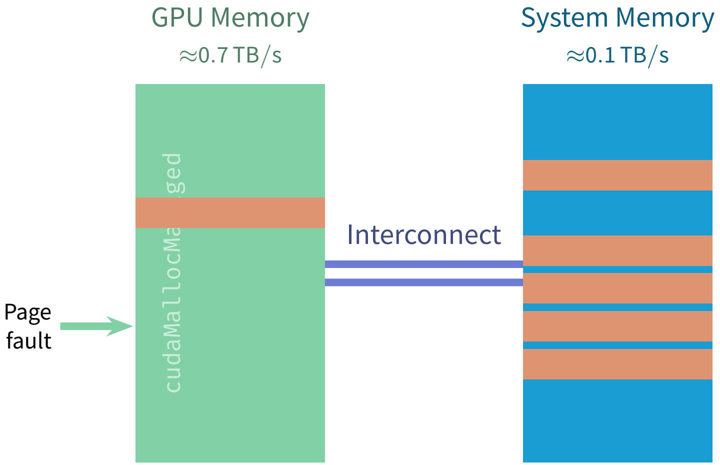

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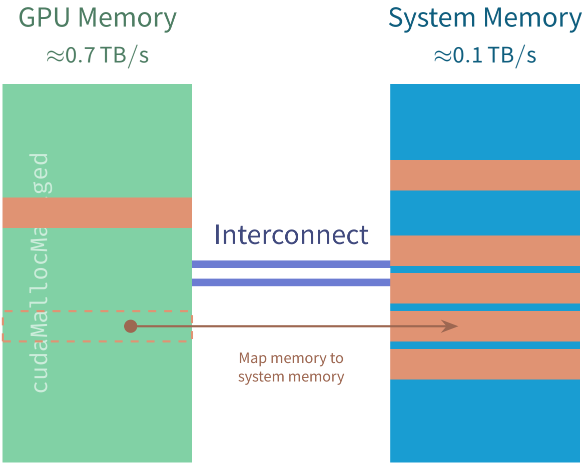

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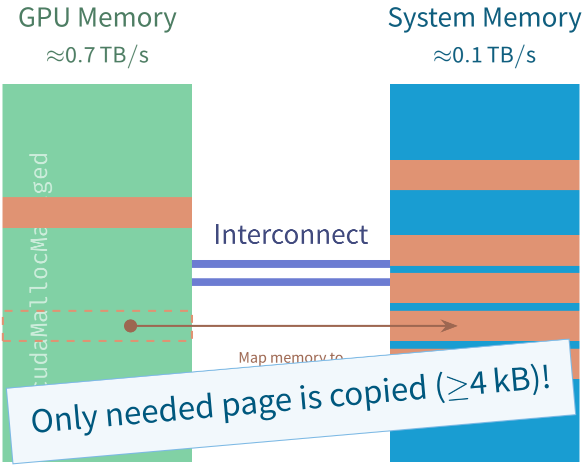
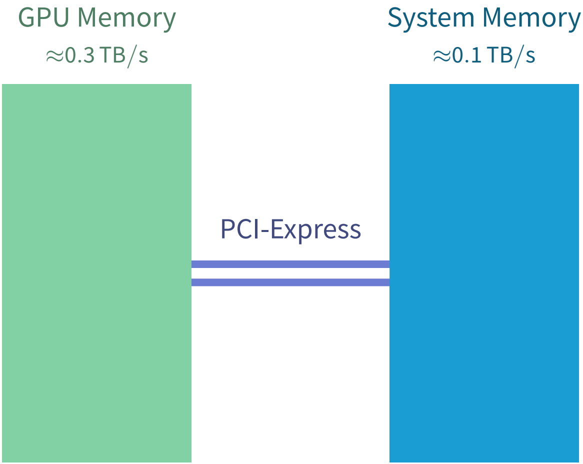


Migration on Kepler



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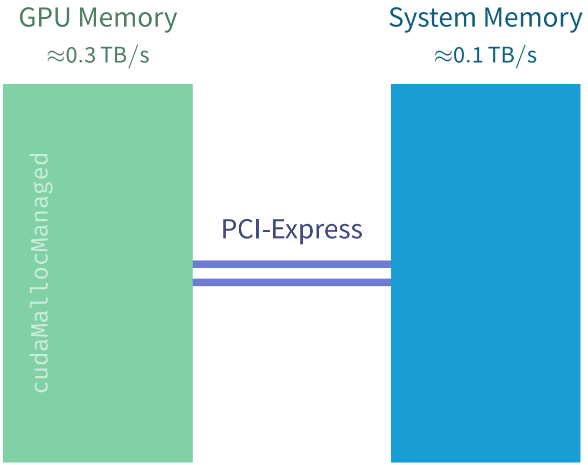

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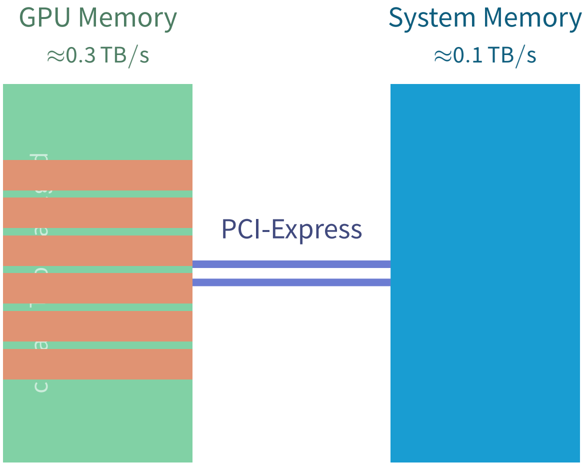

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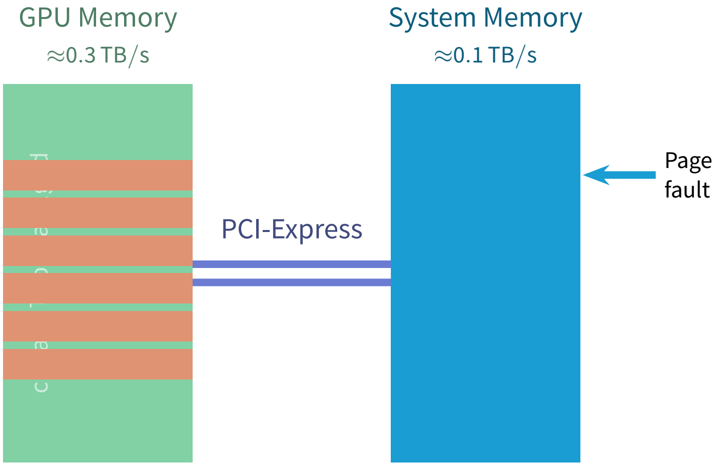

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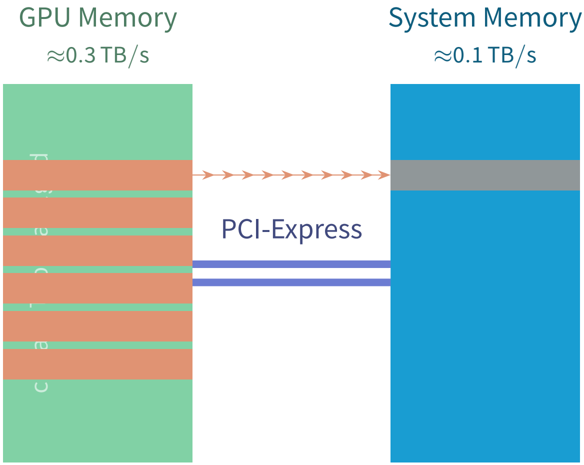

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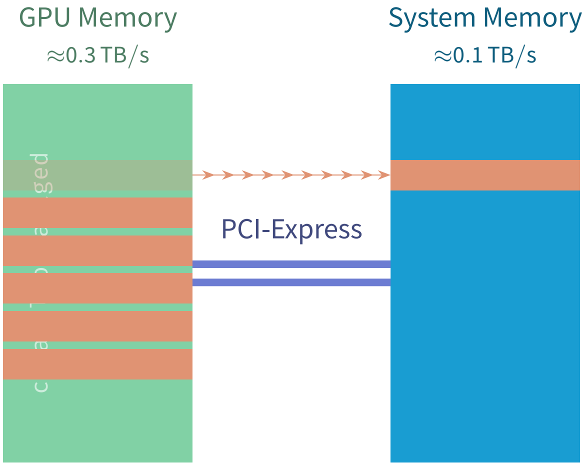

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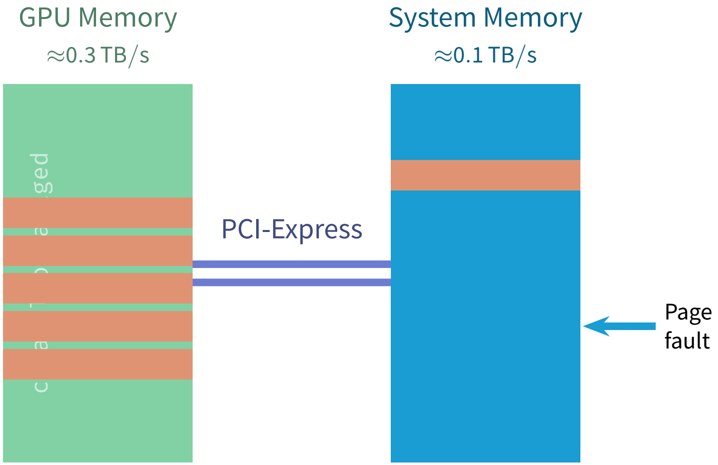

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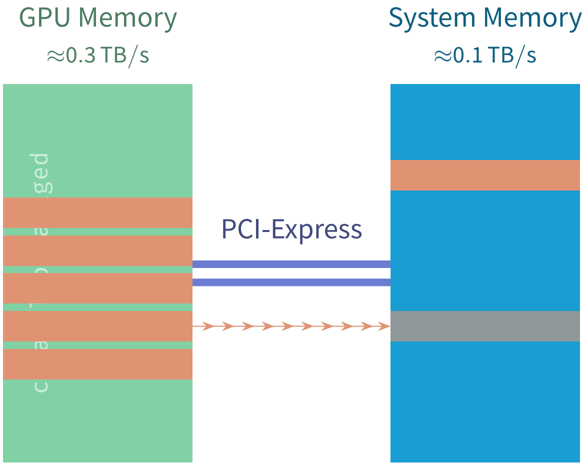

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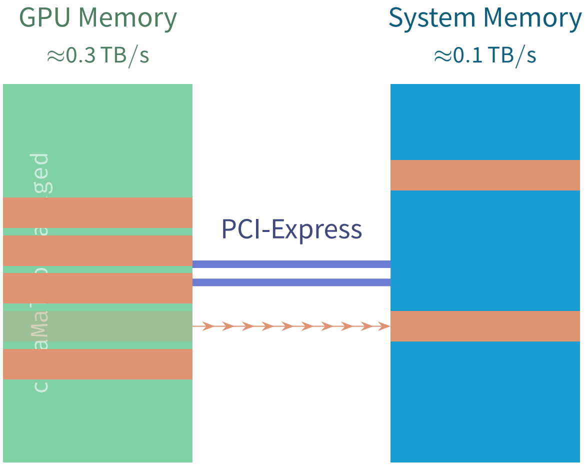

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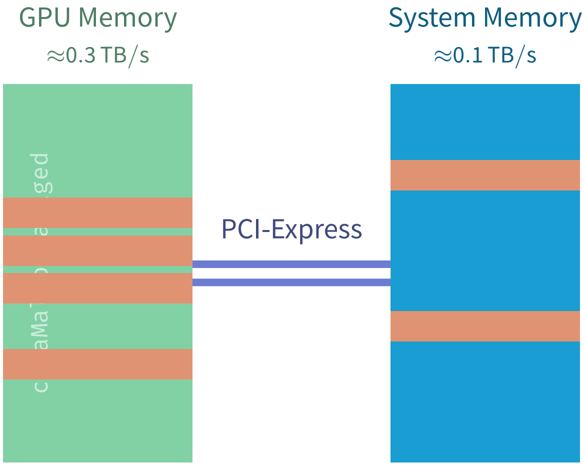

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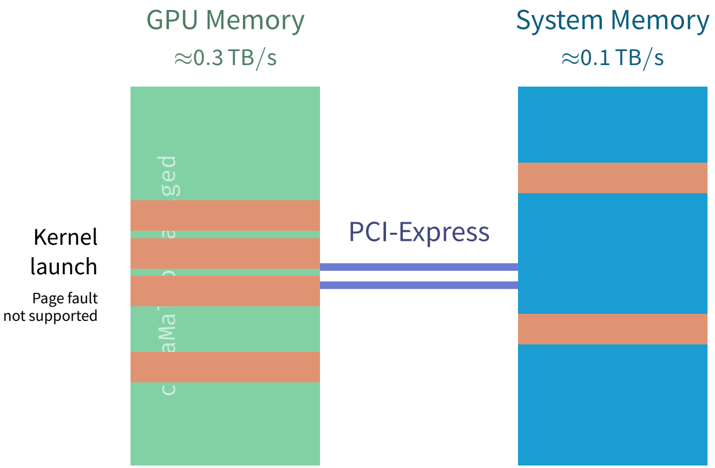

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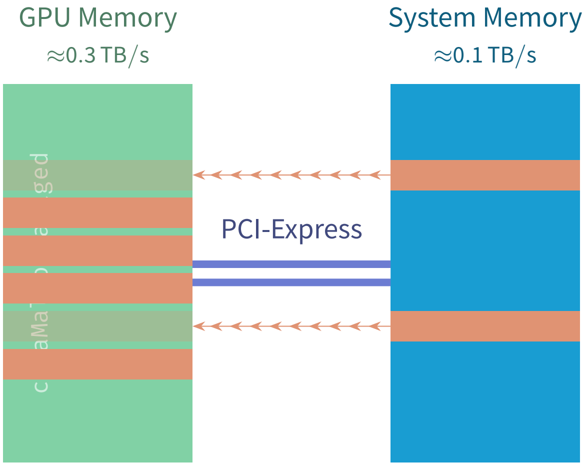

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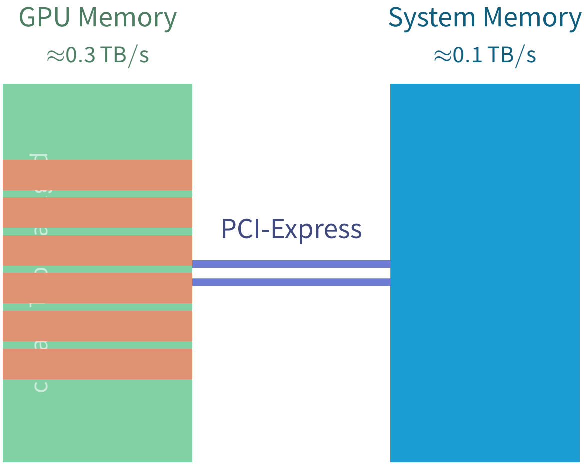


Implementation before Pascal

Kepler (JURECA), Maxwell, …

- Pages populate on GPU with `cudaMallocManaged()`

→ Might migrate to CPU if touched there first

- Pages migrate <u>in bulk</u> to GPU on kernel launch
- No over-subscription possible

Practical Differences

Revisiting `scale_vector_um` Example

Member of the Helmholtz Association

Comparing UM on Pascal & Kepler

Different scales

Who profiled `scale_vector_um` on JURON, who on JURECA?
→ What are run times for kernel?

JURON

```
==109924== Profiling result:
Time(%)      Time     Calls       Avg       Min       Max  Name
100.00%  519.36us         1  519.36us  519.36us  519.36us  scale(float, float*, flo
```

Why?!

Shouldn't P100 be about 3× faster than K80?

JURECA

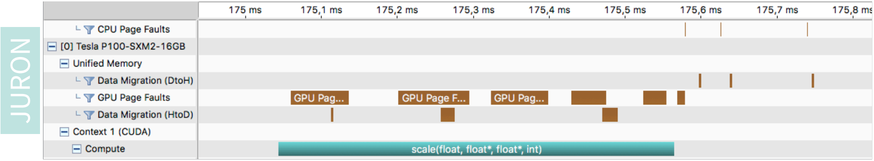
```
==12922== Profiling result:
Time(%)      Time     Calls       Avg       Min       Max  Name
100.00%  13.216us         1  13.216us  13.216us  13.216us  scale(float, float*, flo
```

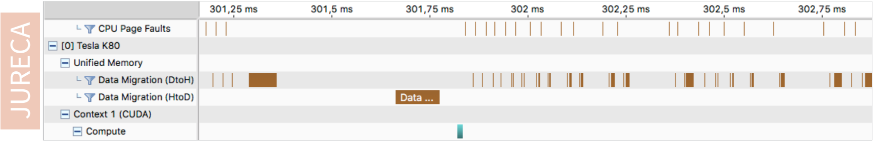
Comparing UM on Pascal & Kepler

Different `scales`

Who profiled `scale_vector_um` on JURON, who on JURECA?

→ What are run times for kernel?





Comparing UM on Pascal & Kepler

What happens?

JURON Kernel is launched, data is needed by kernel, data migrates host→device
⇒ Run time of kernel **incorporates** time for data transfers

JURECA Data will be needed by kernel – so data migrates host→device **before** kernel launch
⇒ Run time of **kernel** without any transfers

- Implementation on Pascal is the more convenient one
- Total run time of whole program does not principally change
  Except it gets shorter because of faster architecture
- But data transfers sometimes sorted to kernel launch

⇒ *What can we do about this?*

Performance Hints for UM

General hints

- **Keep data local**
  Prevent migrations at all if data is processed by close processor
- **Minimize thrashing**
  Constant migrations hurt performance
- **Minimize page fault overhead**
  Fault handling costs $\mathcal{O}(10\,\mu\mathrm{s})$, stalls execution

Performance Hints for UM

New API routines

New API calls to augment data location knowledge of runtime

- `cudaMemPrefetchAsync(data, length, device, stream)`
  Prefetches data to `device` (on `stream`) asynchronously
- `cudaMemAdvise(data, length, advice, device)`
  Advise about usage of given data, `advice`:
  - `cudaMemAdviseSetReadMostly`: Data is mostly read and occasionally written to
  - `cudaMemAdviseSetPreferredLocation`: Set preferred location to avoid migrations; first access will establish mapping
  - `cudaMemAdviseSetAccessedBy`: Data is accessed by *this* device; will pre-map data to avoid page fault
- Use `cudaCpuDeviceId` for `device` CPU, or use `cudaGetDevice()` as usual to retrieve current GPU device id (default: 0)

Hints in Code

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```
void sortfile(FILE *fp, int N) {
    char *data;
    // ...
    cudaMallocManaged(&data, N);

    fread(data, 1, N, fp);

    cudaMemAdvise(data, N, cudaMemAdviseSetReadMostly, device);
    cudaMemPrefetchAsync(data, N, device);
    kernel<<<...>>>(data, N);
    cudaDeviceSynchronize();

    host_func(data);
    cudaFree(data); }
```

Read-only copy of data is created on GPU during prefetch → CPU and GPU reads will not fault

Prefetch data to avoid expensive GPU page faults

Tuning `scale_vector_um`

Express data movement

TASK

- Location of code: `Unified_Memory/exercises/tasks/scale/`
- Look at `Instructions.rst` for instructions
  1. Show runtime that data should be migrated to GPU before kernel call
  2. Build with `make` (CUDA needs to be loaded!)
  3. Run with `make run`

     Or `bsub -I -R "rusage[ngpus_shared=1]" ./scale_vector_um`
  4. Generate profile to study your progress – see `make profile`
- See also CUDA C programming guide for details on data usage

Finished early? There's one more task in the appendix!

Conclusions

What we've learned

- **Unified Memory** is implemented differently on Pascal (JURON) and Kepler (JURECA)
- With CUDA 8.0, there are new API calls to express **data locality**

Thank you for your attention!

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Appendix

Jacobi Task

Glossary

Jacobi Task

One more time…

TASK

- Location of code: `Unified_Memory/exercises/tasks/jacobi/`
- See Jiri Kraus' slides on Unified Memory from last year at `Unified_Memory/exercises/slides/jkraus-unified_memory-2016.pdf`
- Short instructions
  - Avoid data migrations in while loop of Jacobi solver: apply boundary conditions with provided GPU kernel; try to avoid remaining migrations
  - Build with `make` (CUDA needs to be loaded!)
  - Run with `make run`
  - Look at profile – see `make profile`

Glossary I

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API A programmatic interface to software by well-defined functions. Short for application programming interface. 53

ATI Canada-based GPUs manufacturing company; bought by AMD in 2006. 53

CUDA Computing platform for GPUs from NVIDIA. Provides, among others, CUDA C/C++. 4, 5, 49, 50, 53

GCC The GNU Compiler Collection, the collection of open source compilers, among other for C and Fortran. 53

Glossary II

LLVM An open Source compiler infrastructure, providing, among others, Clang for C. 53

NVIDIA US technology company creating GPUs. 53

NVLink NVIDIA's communication protocol connecting CPU ↔ GPU and GPU ↔ GPU with 80 GB/s. PCI-Express: 16 GB/s. 53

OpenACC Directive-based programming, primarily for many-core machines. 53

OpenCL The *Open Computing Language*. Framework for writing code for heterogeneous architectures (CPU, GPU, DSP, FPGA). The alternative to CUDA. 53

Glossary III

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OpenGL The *Open Graphics Library*, an API for rendering graphics across different hardware architectures. 53

OpenMP Directive-based programming, primarily for multi-threaded machines. 53

P100 A large GPU with the Pascal architecture from NVIDIA. It employs NVLink as its interconnect and has fast *HBM2* memory. 53

SAXPY Single-precision $A \times X + Y$. A simple code example of scaling a vector and adding an offset. 53

Tesla The GPU product line for general purpose computing computing of NVIDIA. 53

Glossary IV

Thrust A parallel algorithms library for (among others) GPUs. See `https://thrust.github.io/`. 53