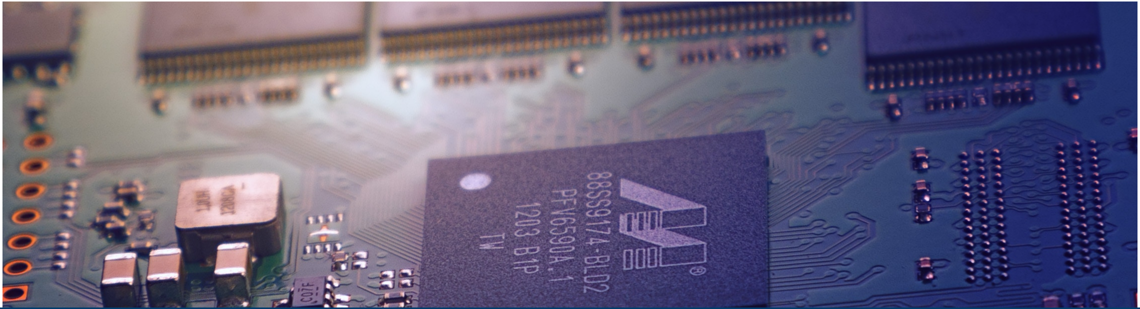


UNIFIED MEMORY
NOTES ON GPU DATA TRANSFERS

23 April 2018 | Andreas Herten | Forschungszentrum Jülich

JÜLICH Forschungszentrum | JÜLICH SUPERCOMPUTING CENTRE

Overview, Outline

Overview

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

Contents

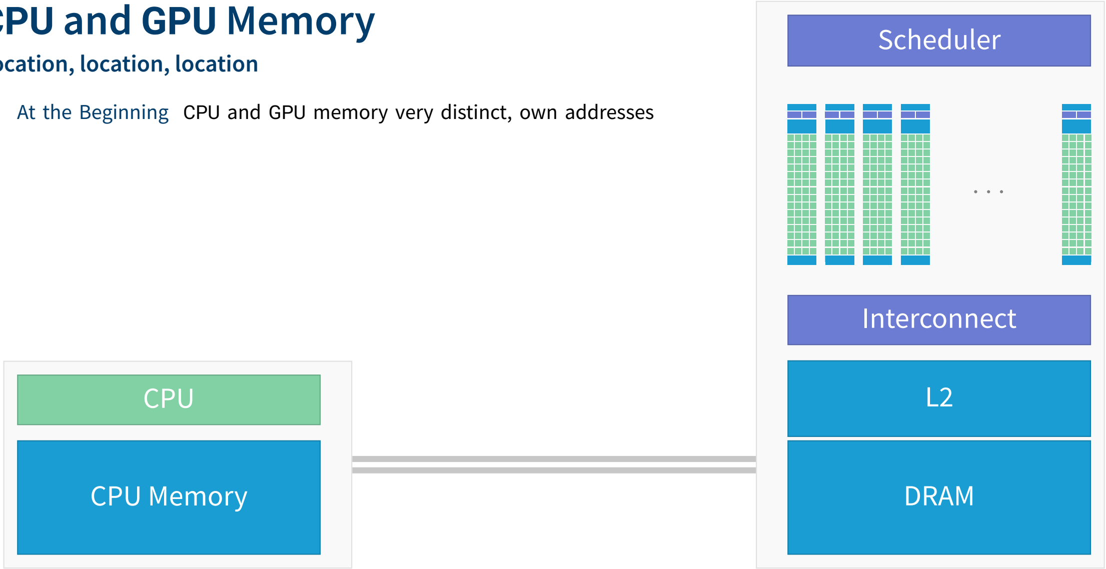
Background on Unified Memory

History of GPU Memory

CPU and GPU Memory

Location, location, location

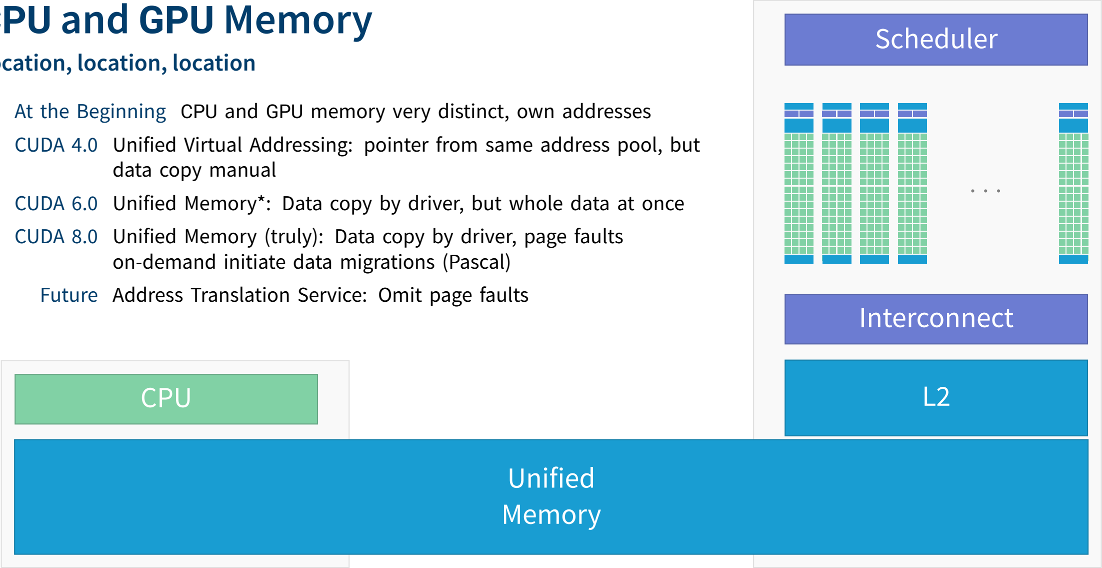
At the Beginning CPU and GPU memory very distinct, own addresses



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)
- **Future** Address Translation Service: Omit page faults



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

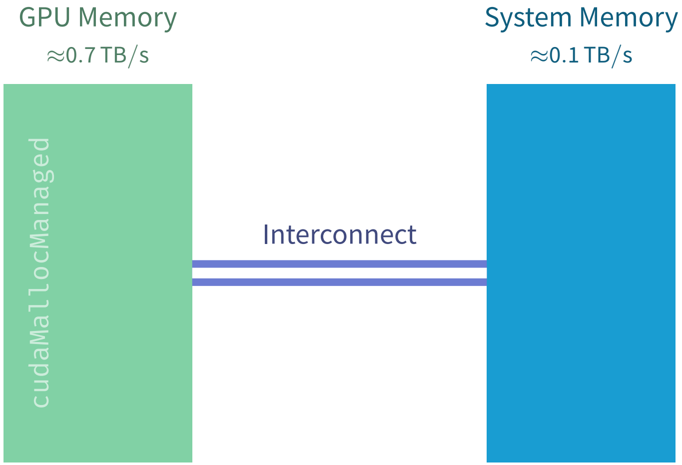
```
cudaMallocManaged(&ptr, ...);
```
Empty! No pages anywhere yet (like `malloc( )`)

```
*ptr = 1;
```
CPU page fault: data allocates on CPU

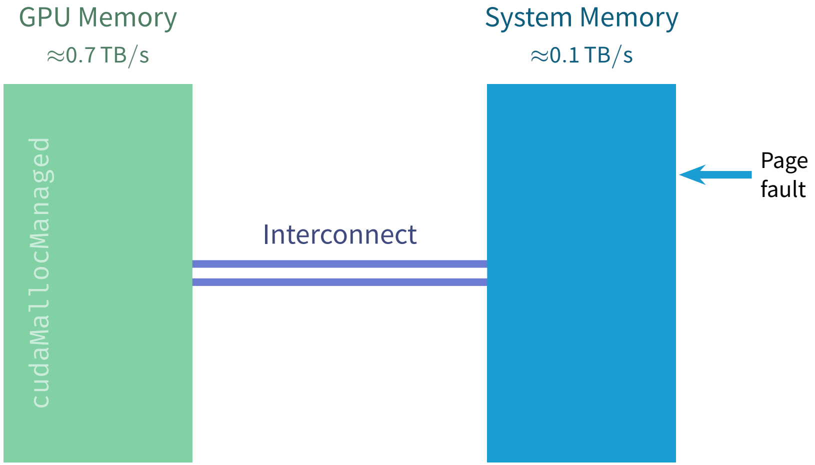
```
kernel<<<...>>>(ptr);
```
GPU page fault: data migrates to GPU

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

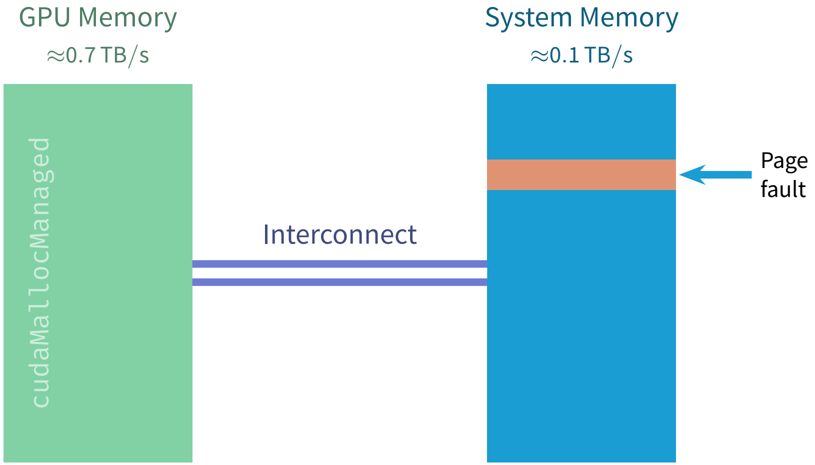
On-Demand Migration Flow at Pascal



On-Demand Migration Flow at Pascal



On-Demand Migration Flow at Pascal



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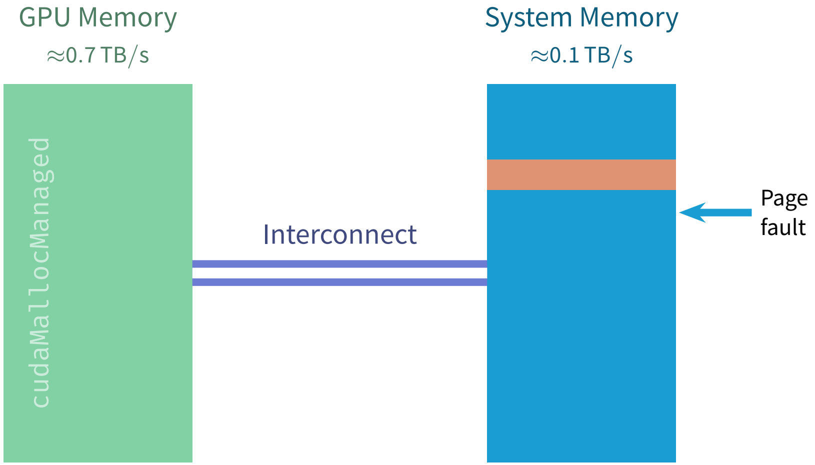
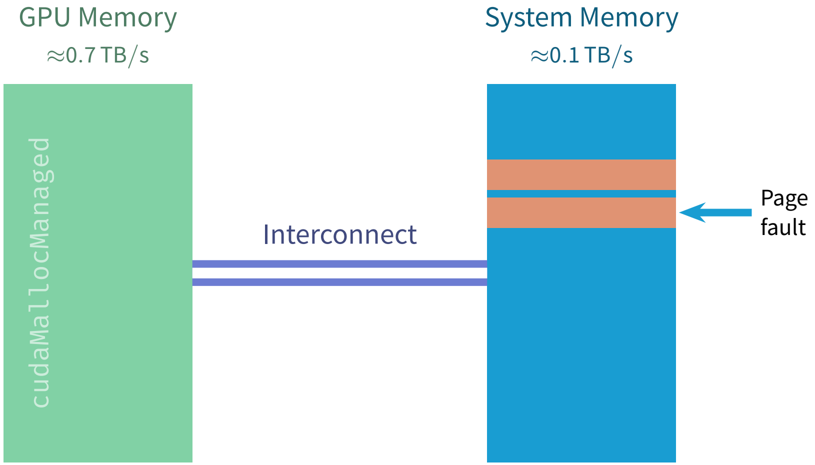
On-Demand Migration Flow at Pascal



On-Demand Migration Flow at Pascal



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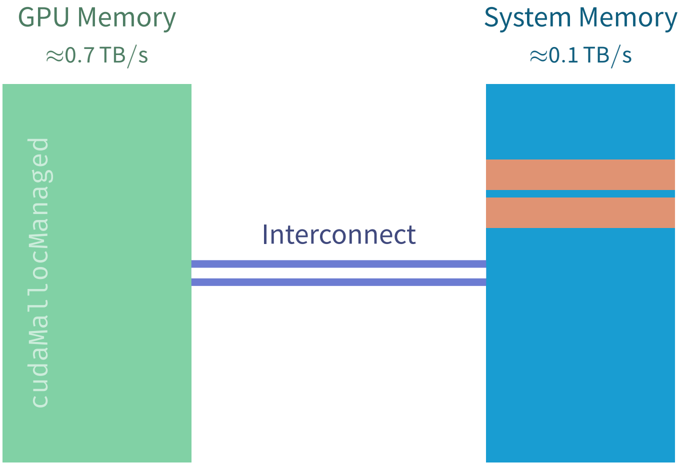

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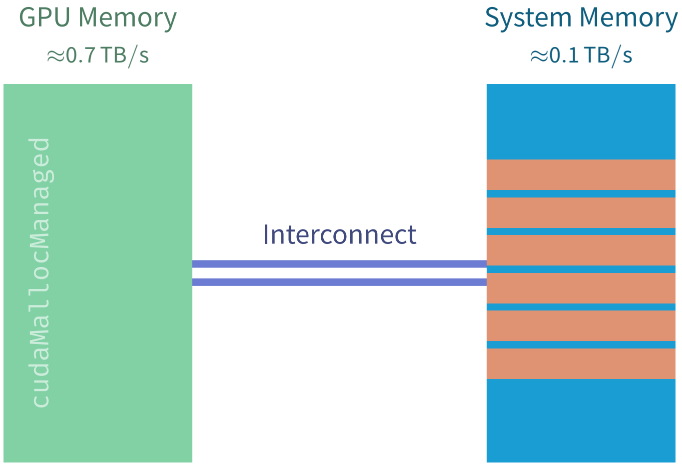

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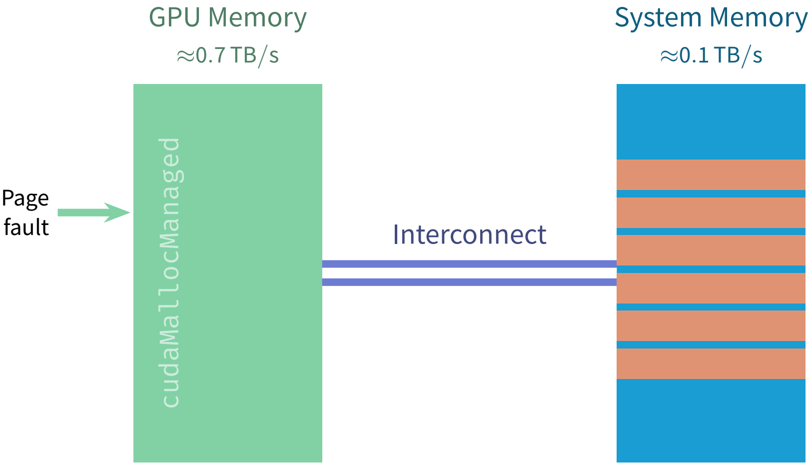

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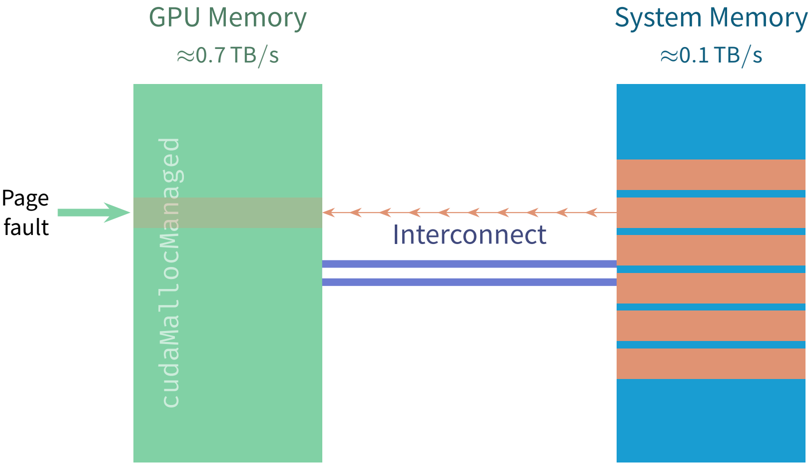

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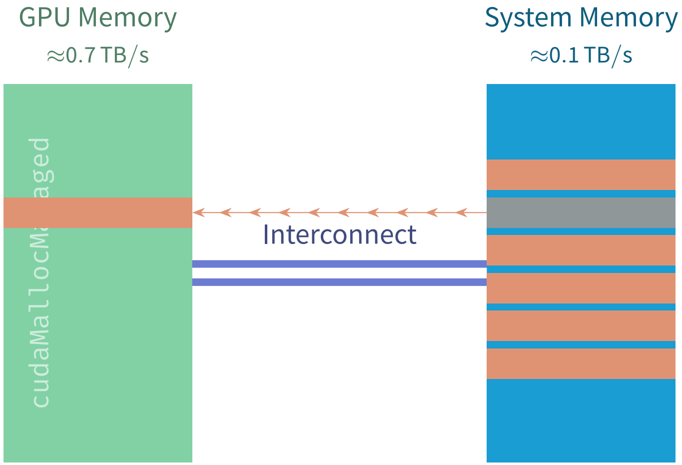

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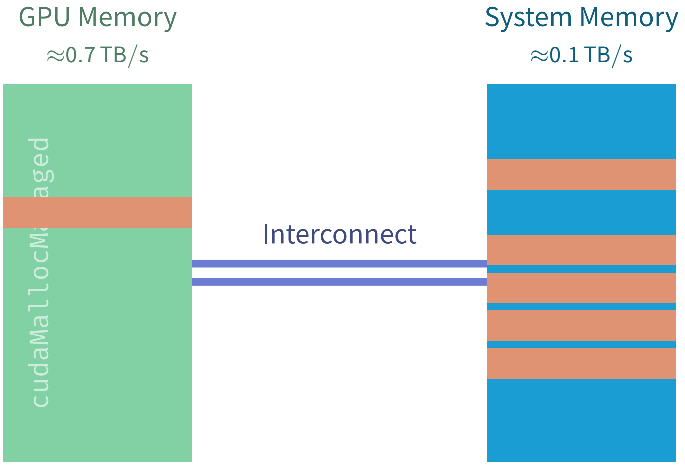
On-Demand Migration Flow at Pascal



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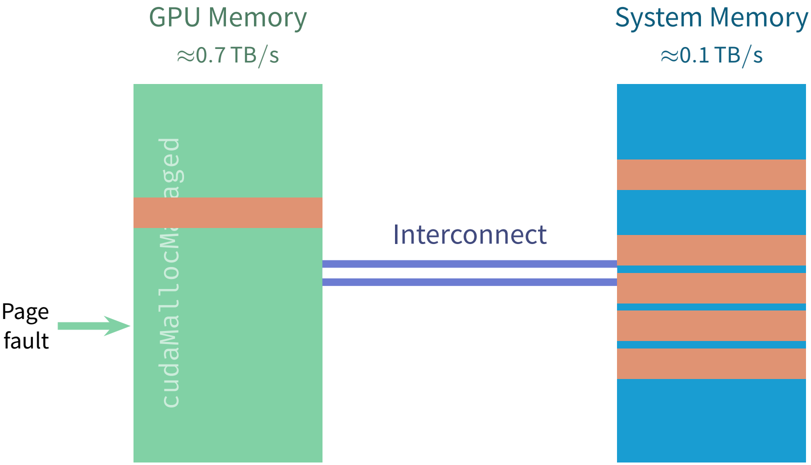

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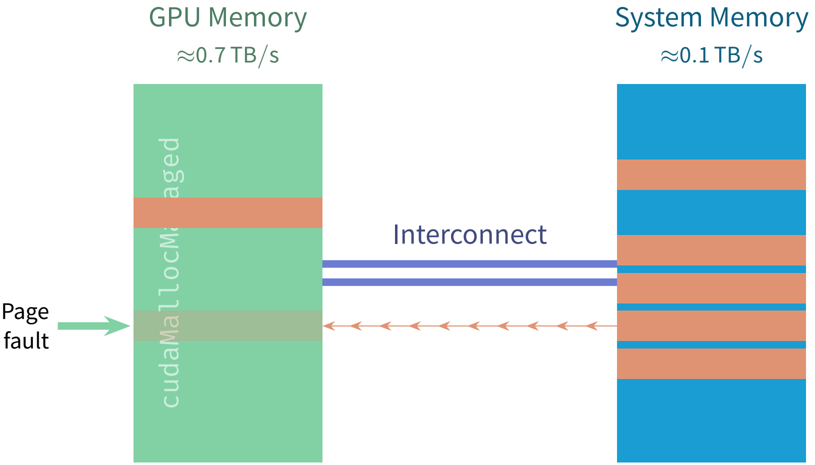

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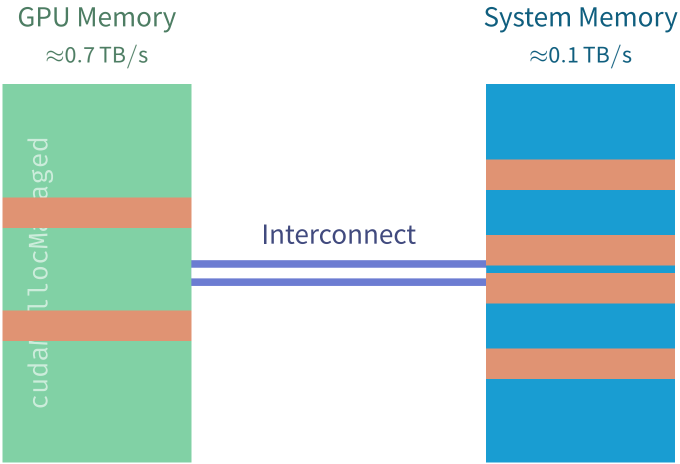
On-Demand Migration Flow at Pascal



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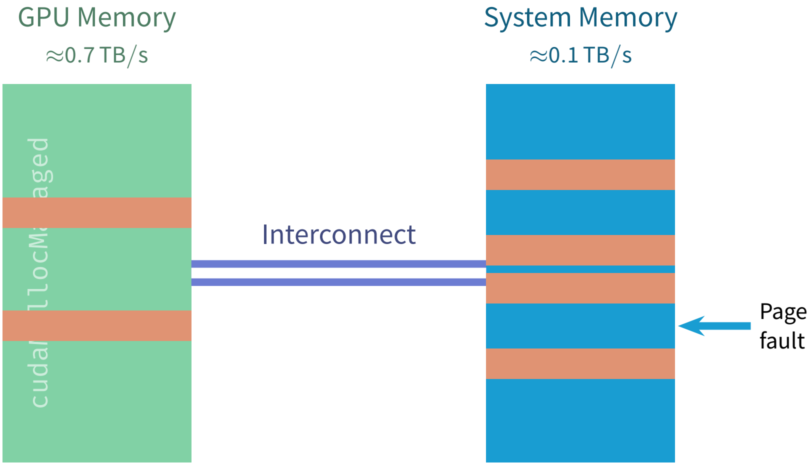

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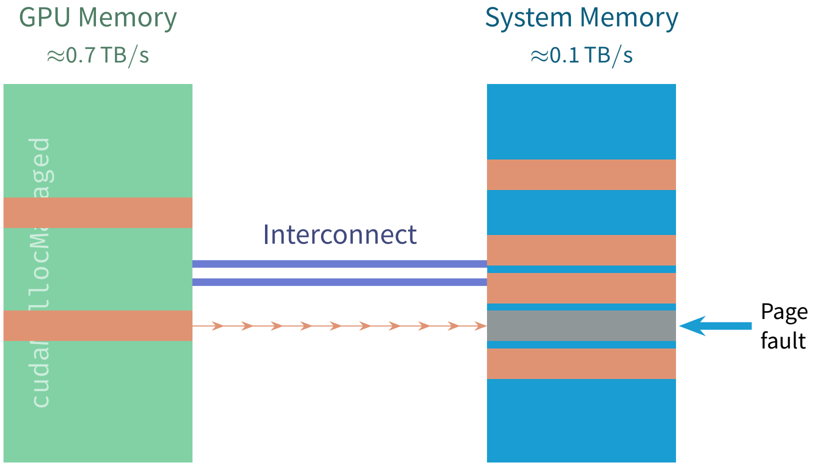

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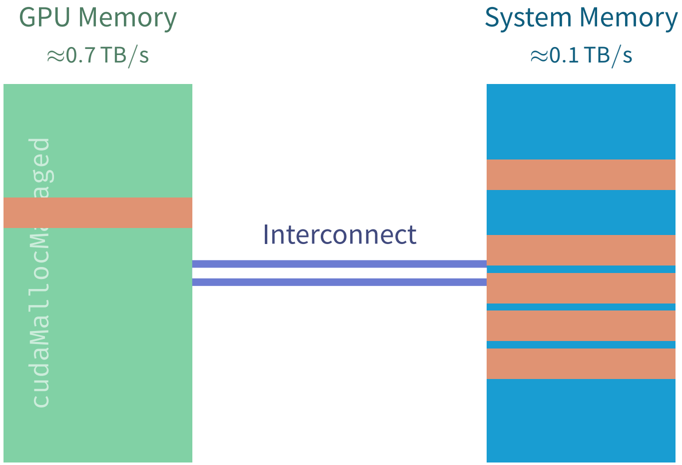

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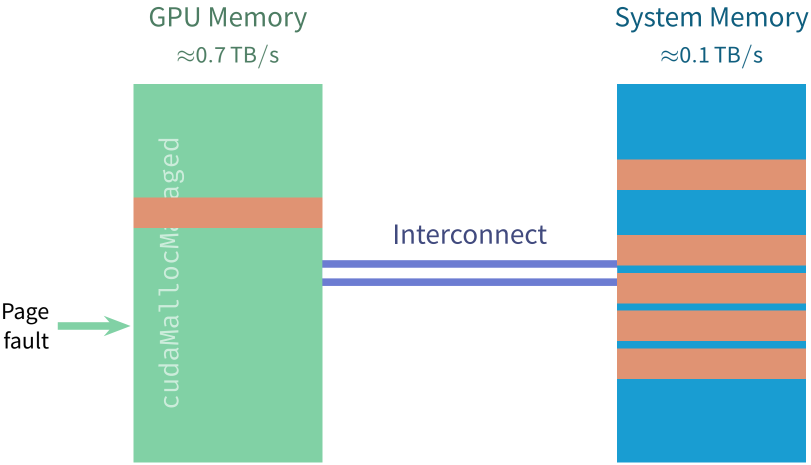
On-Demand Migration Flow at Pascal



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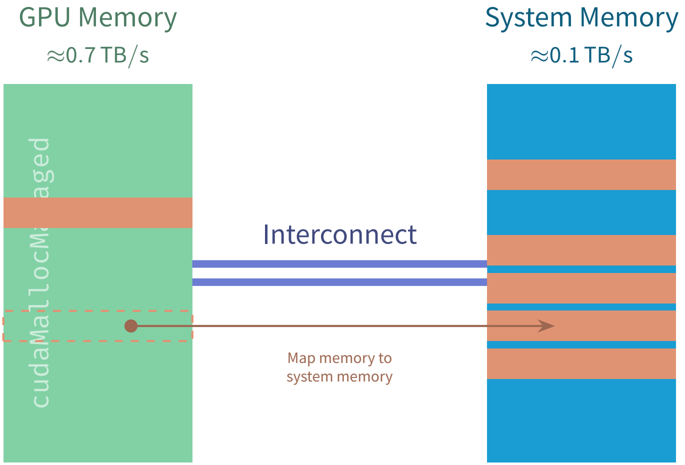

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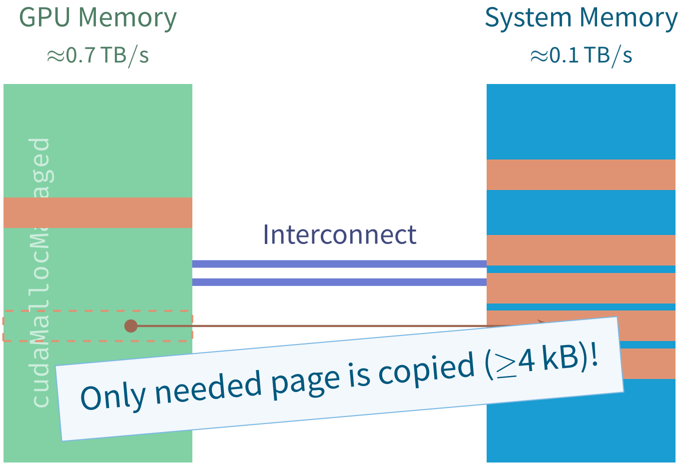
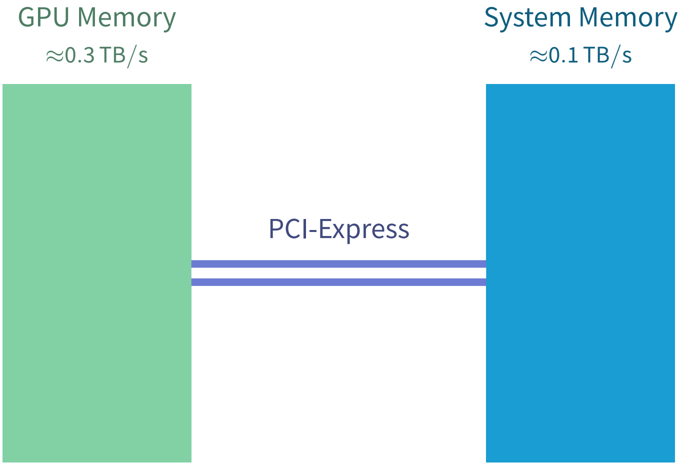
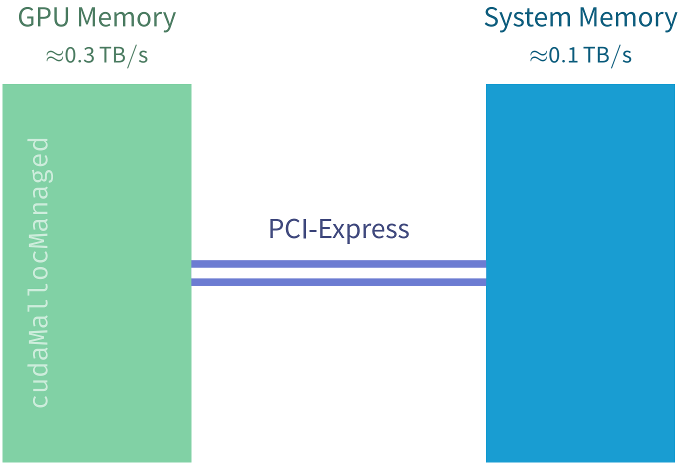
On-Demand Migration Flow at Pascal



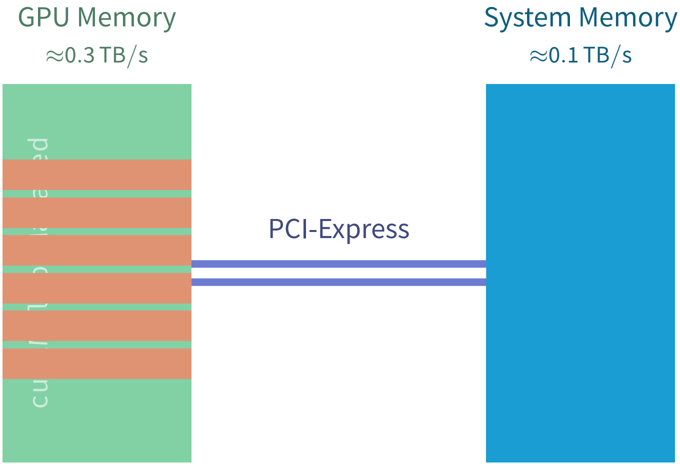
Migration on Kepler



Migration on Kepler



Migration on Kepler



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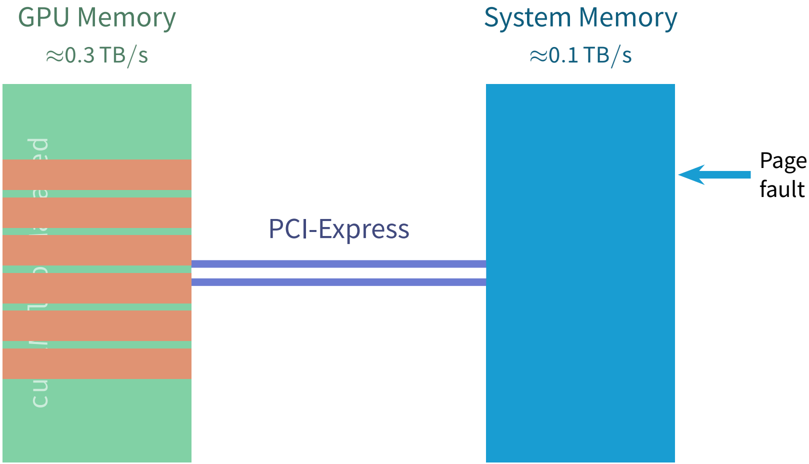
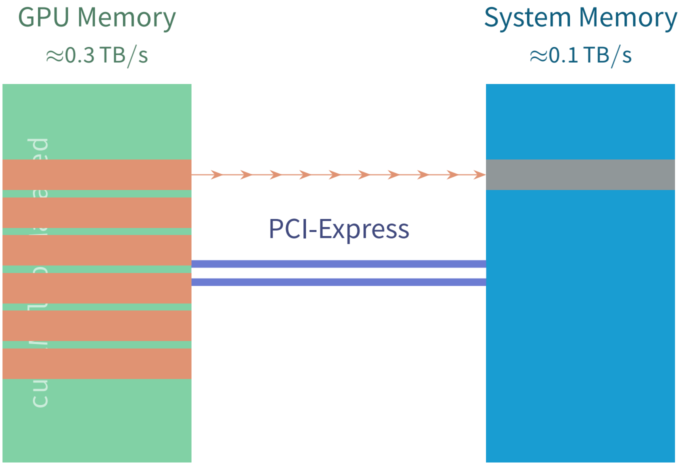
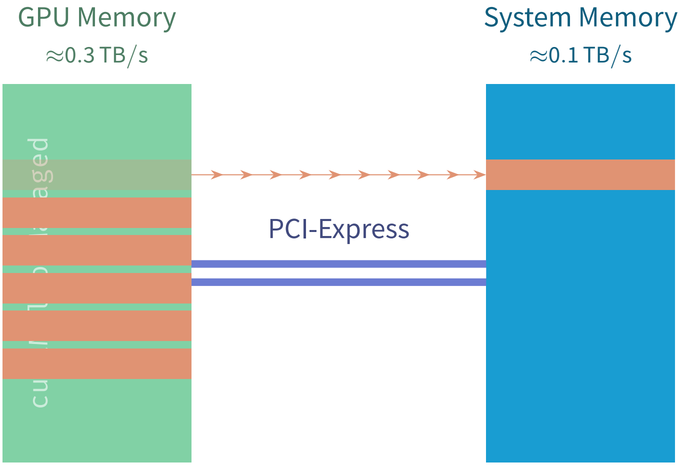
Migration on Kepler



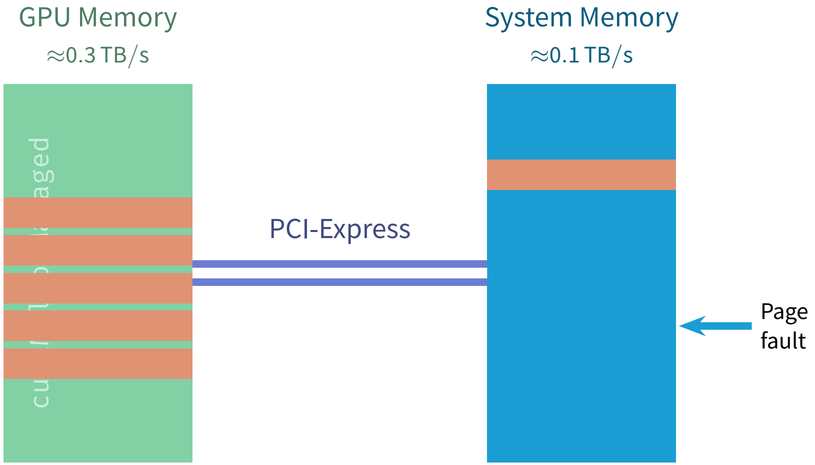
Migration on Kepler



Migration on Kepler



Migration on Kepler



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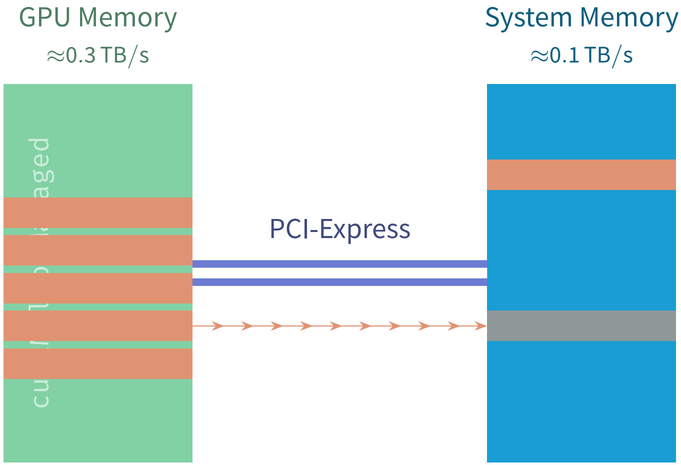

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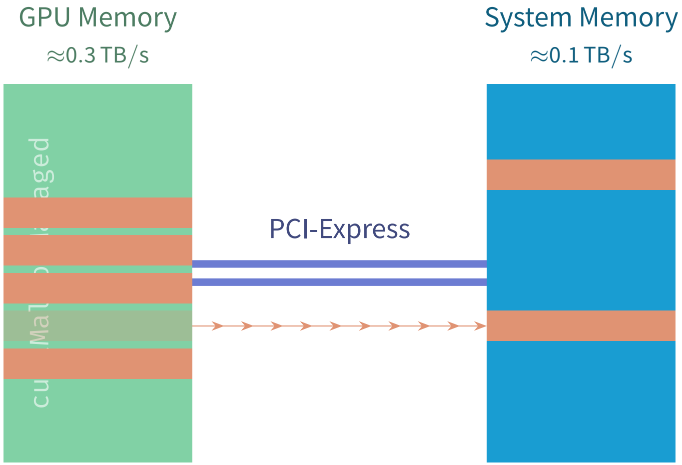
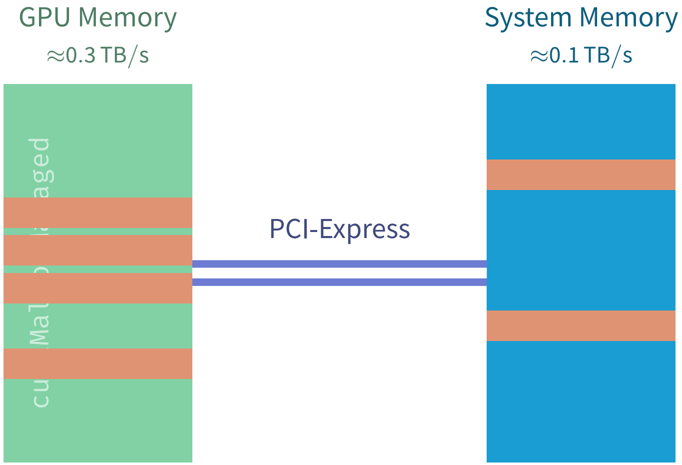


Migration on Kepler



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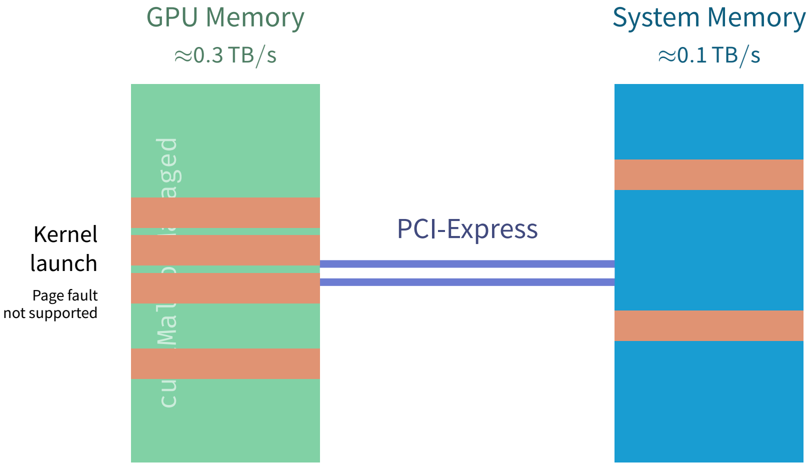
Migration on Kepler



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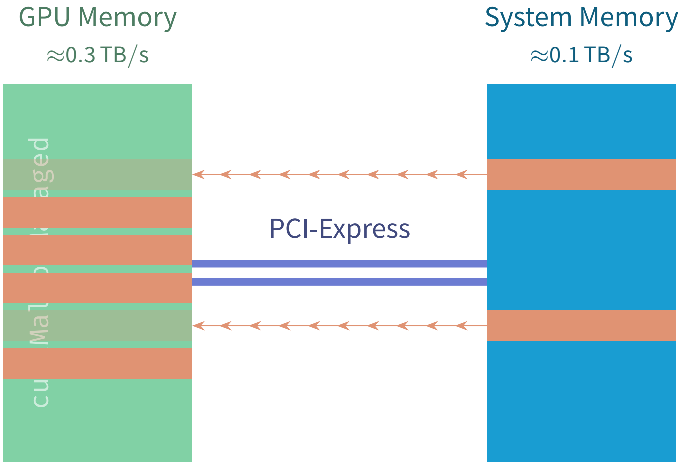
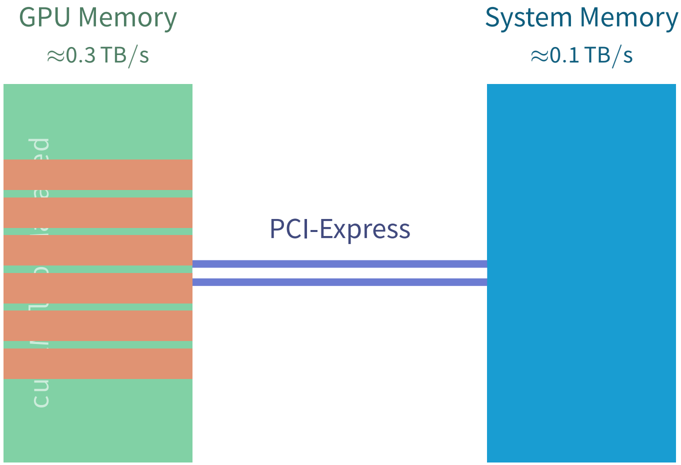
Migration on Kepler



Migration on Kepler



Implementation before Pascal

Kepler (JURECA), Maxwell, …

- Pages populate on GPU with `cudaMallocManaged()`

→ Might migrate to CPU if touched there first

- Pages migrate in bulk to GPU on kernel launch
- No over-subscription possible

Practical Differences

Revisiting `scale_vector_um` Example

Comparing UM on Pascal & Kepler

Different `scales`

Comparing `scale_vector_um` on JURON and JURECA

JURON

```
==109924== Profiling result:
Time(%)      Time     Calls       Avg       Min       Max  Name
100.00%  1.8203ms         1  1.8203ms  1.8203ms  1.8203ms  scale(float, float*, float*, int)
```

Why?!

Shouldn't P100 be about 4× faster than K80?

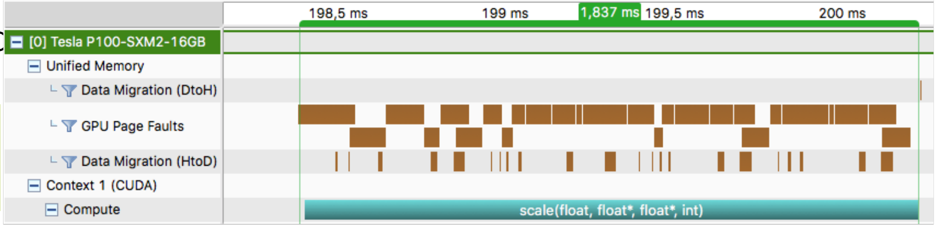
JURECA

```
==12922== Profiling result:
Time(%)      Time     Calls       Avg       Min       Max  Name
100.00%  136.03us         1  136.03us  136.03us  136.03us  scale(float, float*, float*, int)
```

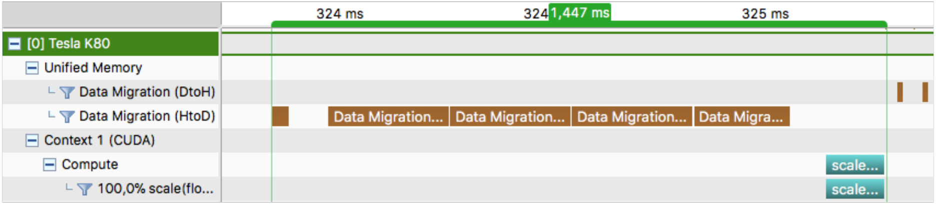
Comparing UM on Pascal & Kepler

Different `scales`

JURON



JURECA



Comparing UM on Pascal & Kepler

What happens?

JURON Kernel is launched, data is needed by kernel, data migrates host$\rightarrow$device
$\Rightarrow$ Run time of kernel **incorporates** time for data transfers

JURECA Data will be needed by kernel – so data migrates host$\rightarrow$device **before** kernel launch
$\Rightarrow$ 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

$\Rightarrow$ *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 $\mathcal{O}\left(10\,\mu\text{s}\right)$, stalls execution

Performance Hints for UM

New API routines

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

```
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`

TASK

Express data movement

- Location of code: `Unified_Memory/exercises/tasks/scale/`
- Look at `Instructions.md` for instructions
  1. Show runtime that data should be migrated to GPU before kernel call
  2. Build with `make`
  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 *productive* feature for GPU programming
- 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!
a.herten@fz-juelich.de

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Appendix

Jacobi Task

Glossary

Jacobi Task

TASK

One more time...

- Location of code: `Unified_Memory/exercises/tasks/jacobi/`
- See Jiri Kraus' slides on Unified Memory from 2016 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

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

JSC Jülich Supercomputing Centre, the supercomputing institute of Forschungszentrum Jülich, Germany. 53

JURECA A multi-purpose supercomputer with 1800 nodes at JSC. 45, 50

JURON One of the two HBP pilot system in Jülich; name derived from Juelich and Neuron. 45, 50

NVIDIA US technology company creating GPUs. 53

Pascal GPU architecture from NVIDIA (announced 2016). 4, 5, 45

Glossary II

CPU Central Processing Unit. 4, 5, 7, 41, 47, 48

GPU Graphics Processing Unit. 2, 3, 4, 5, 7, 41, 47, 48, 49, 50, 52, 53

HBP Human Brain Project. 53

References: Images, Graphics I

[1] Martin Oslic. *Bug*. Freely available at Unsplash. URL: https://unsplash.com/photos/Qi93Pl5vDRw.

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