Pipelining Persistent Kernels

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Agenda

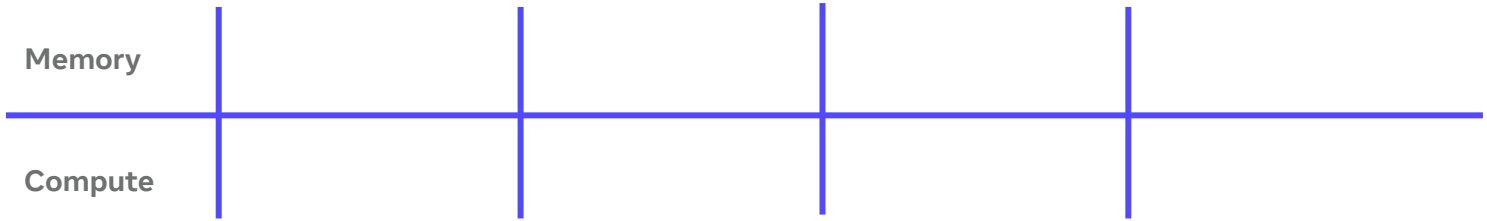
- Software Pipelining
- Persistent Kernels
- Putting the Two Together…
- … Efficiently

Software Pipelining

SOFTWARE PIPELINING

```
for k in range(0, k_tiles):
  a = tl.load(a_ptrs)
  b = tl.load(b_ptrs)
  c = tl.dot(a, b, c)
  a_ptrs, b_ptrs = …
tl.store(c_ptrs, c)
```

SOFTWARE PIPELINING



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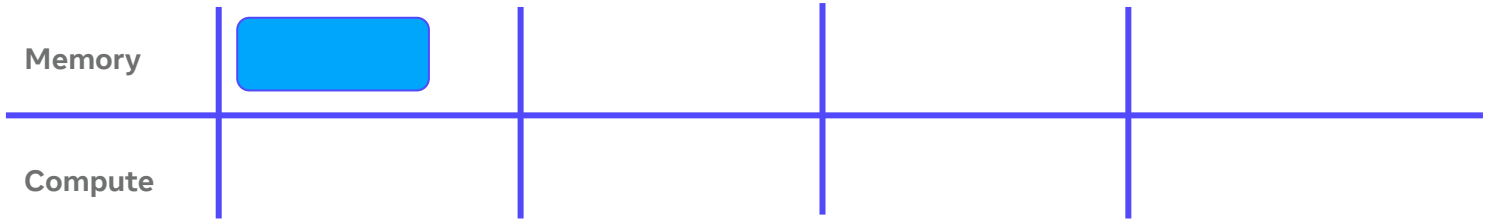

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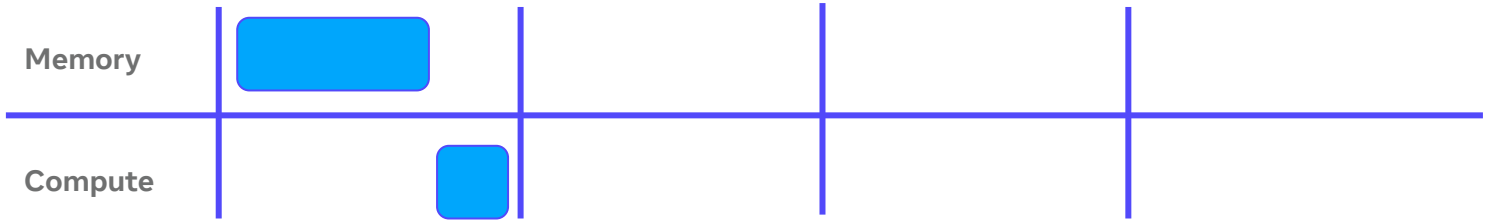

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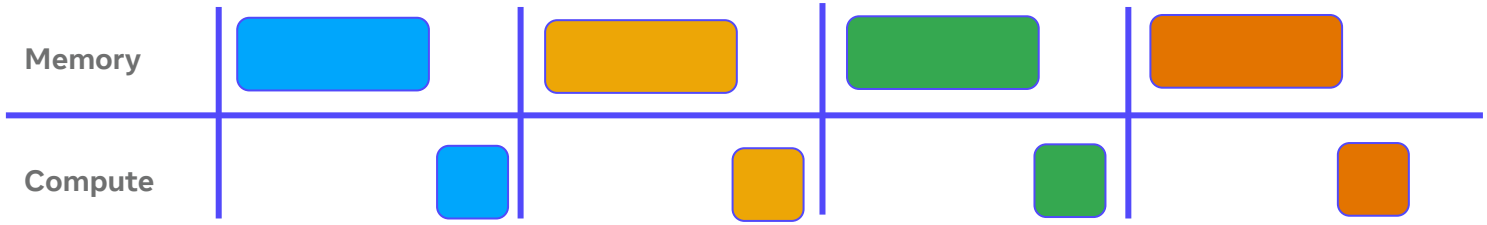

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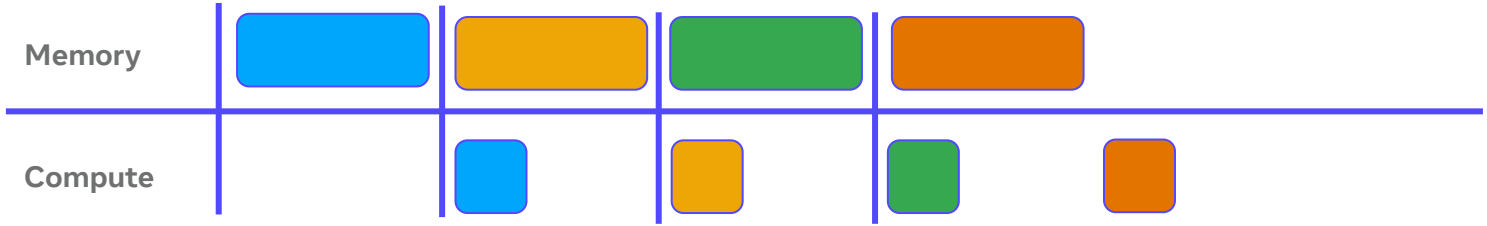

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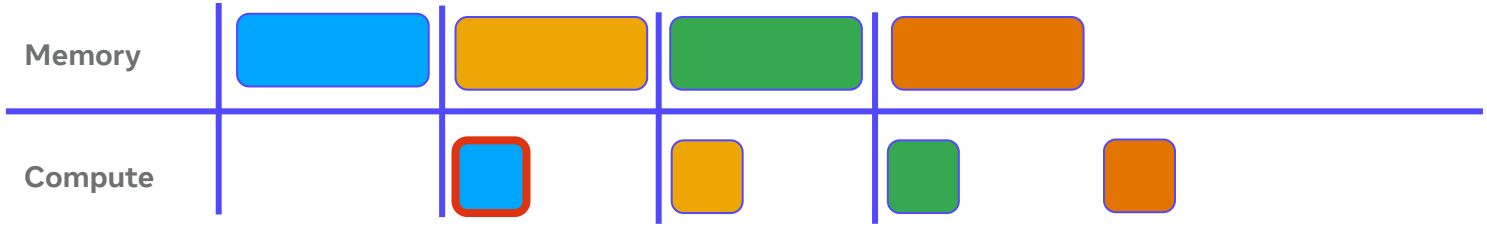

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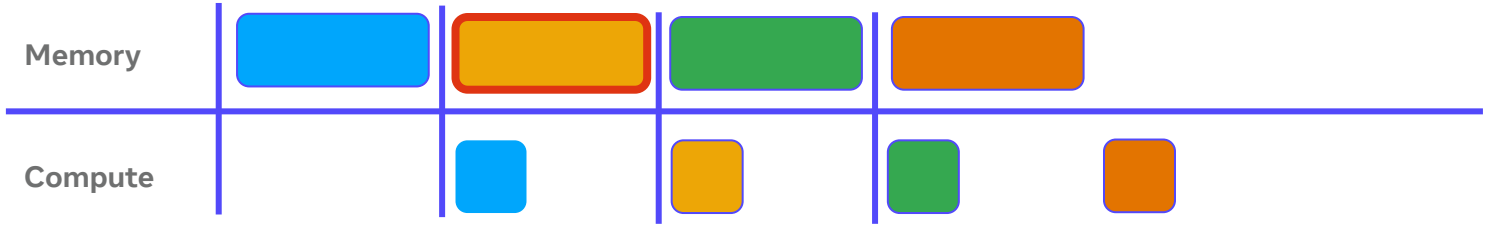

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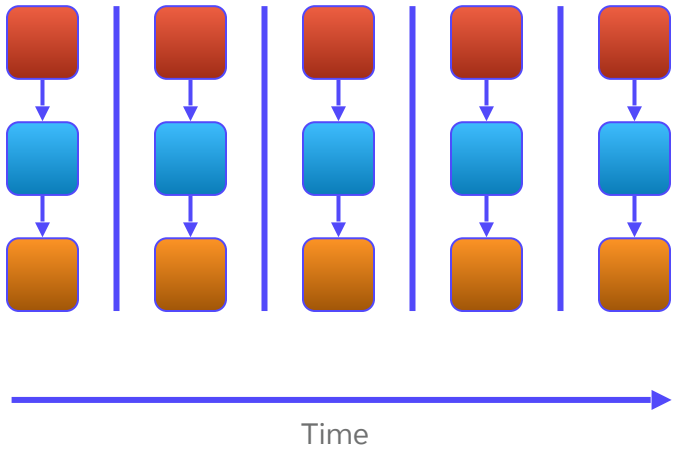

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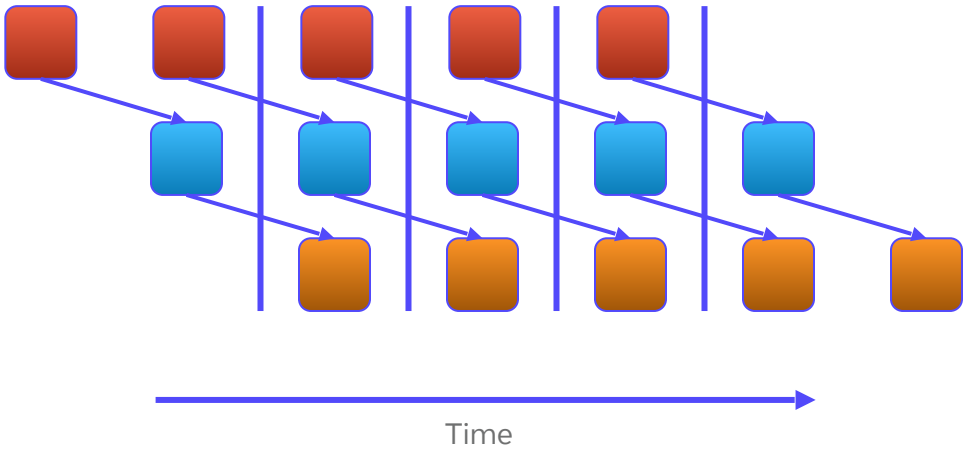

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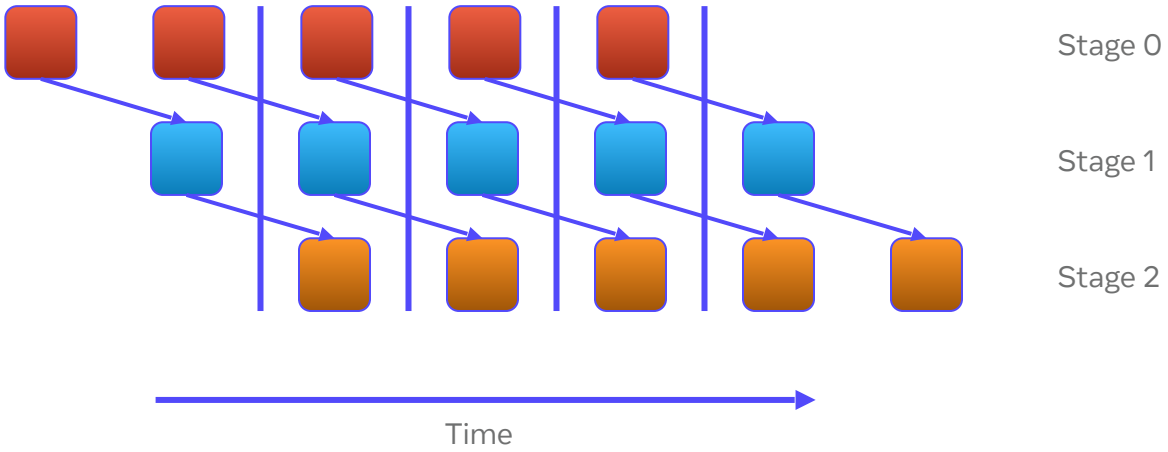

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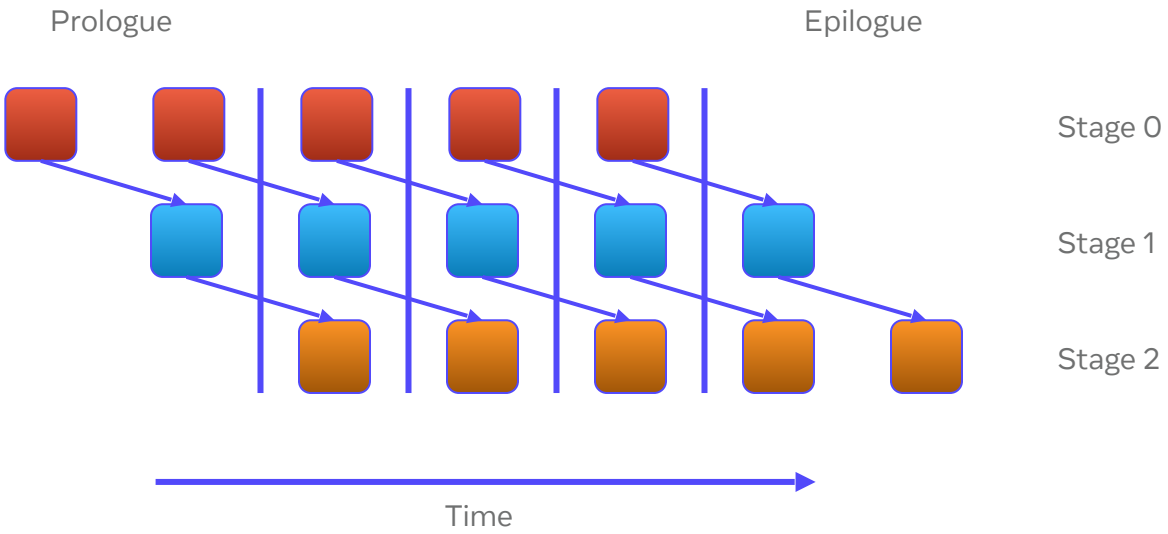
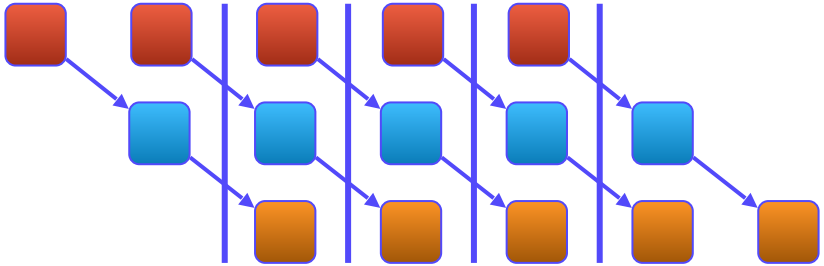


SOFTWARE PIPELINING - PROLOGUE/EPILOGUE PEELING/MASKING



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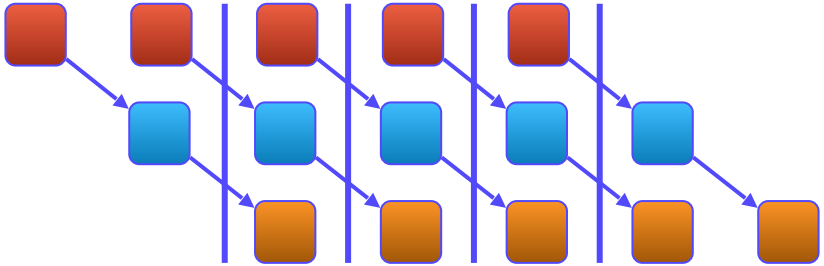

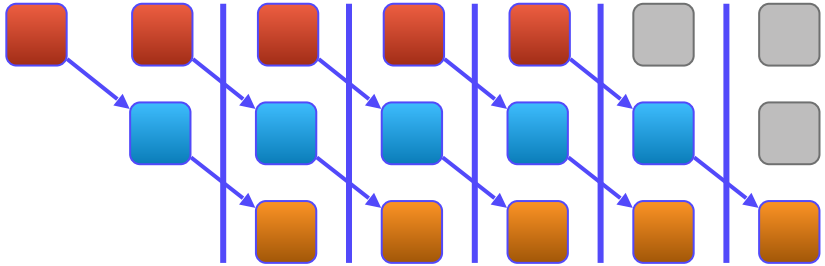

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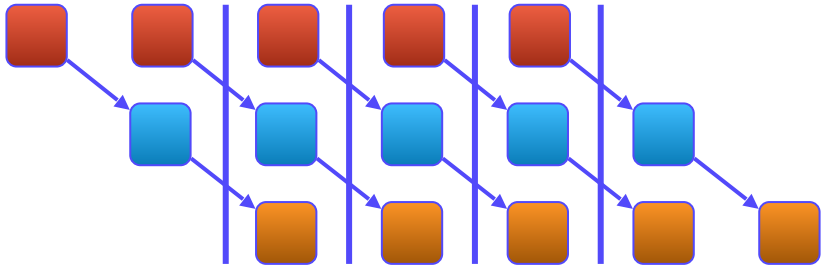

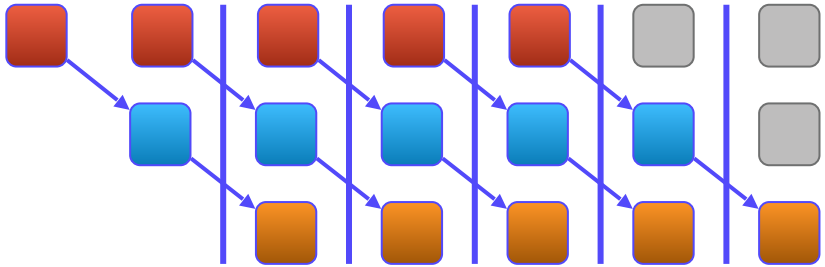

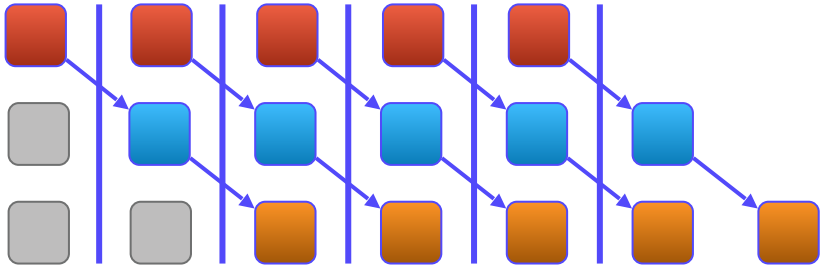

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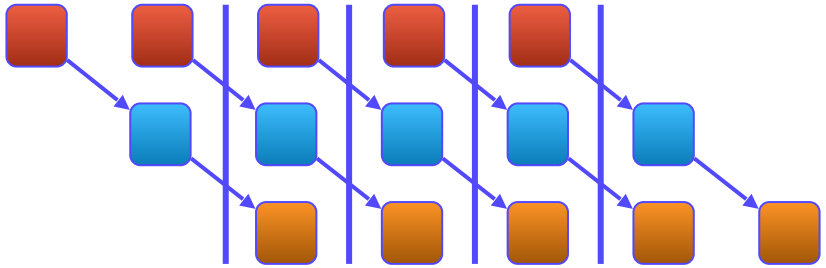

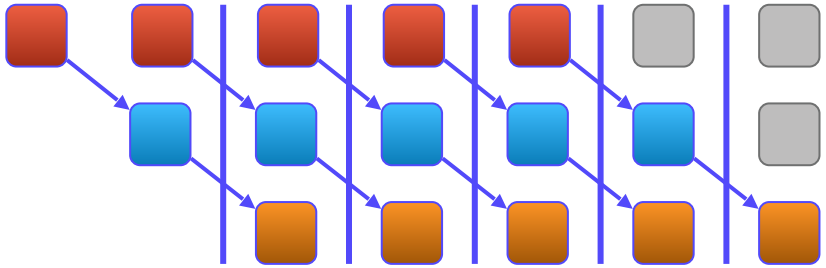

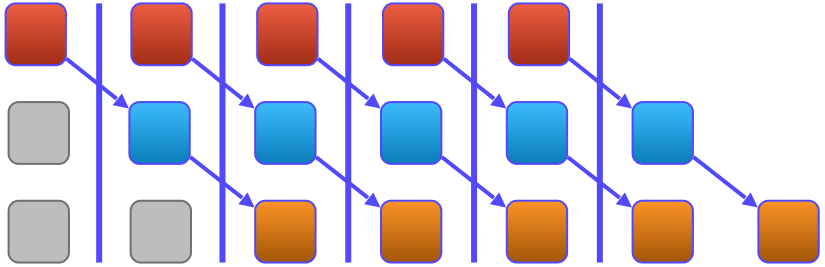

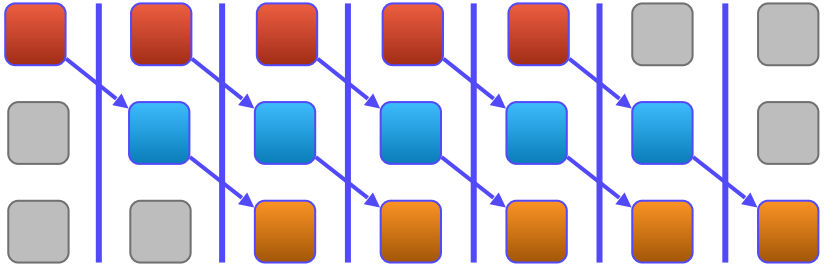

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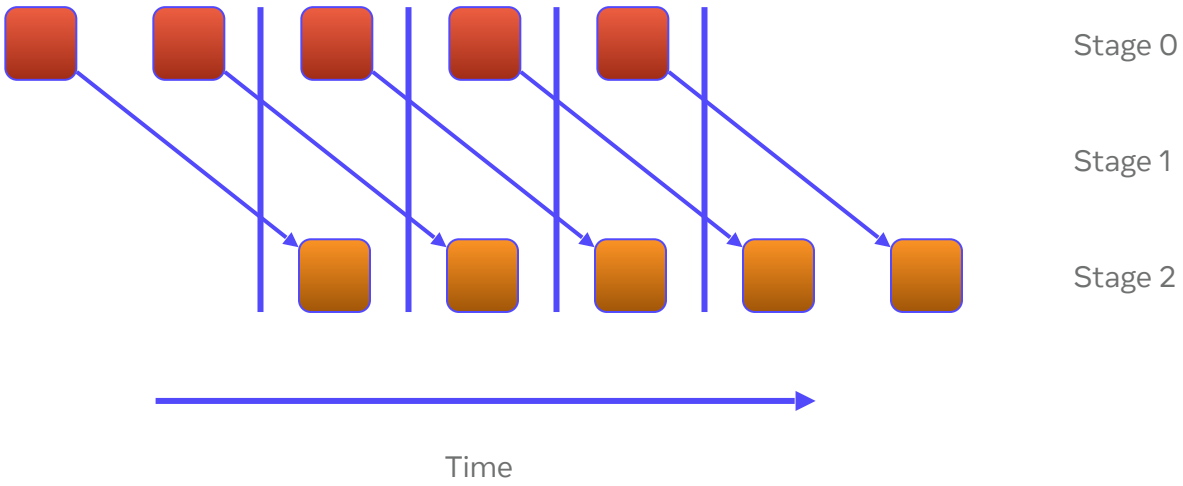
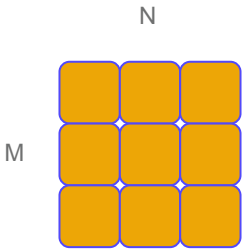


Software Pipelining

- Additional transformations required:
  - Multi buffering
  - Sync → async operations

- Amazing Pipeline Expander in MLIR upstream!

PERSISTENT KERNELS



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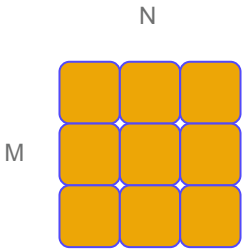

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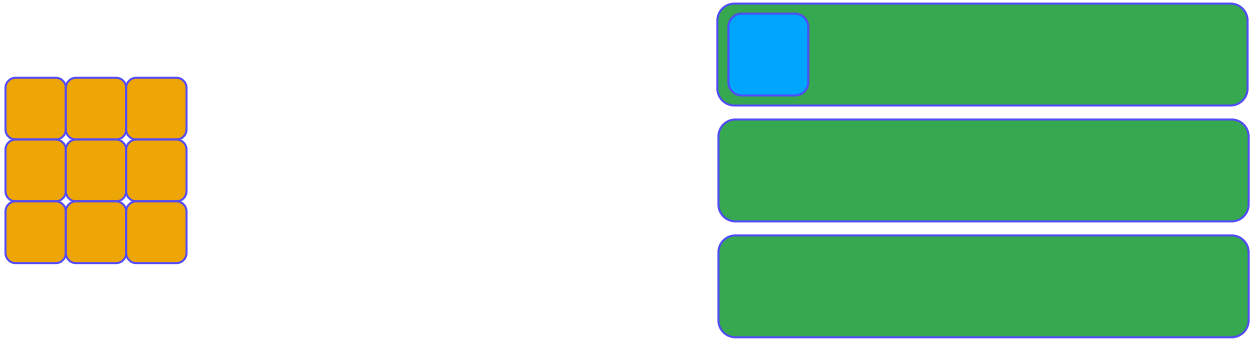

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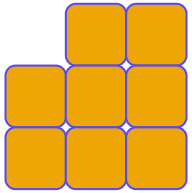

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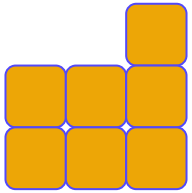

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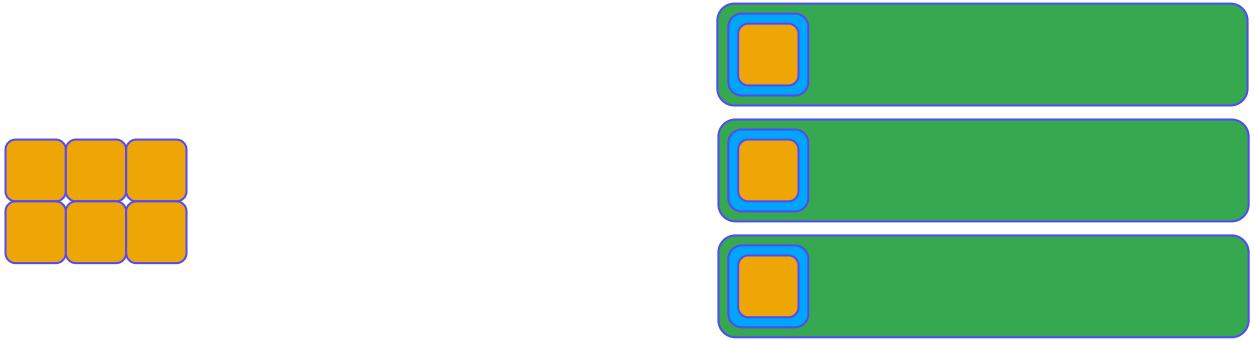

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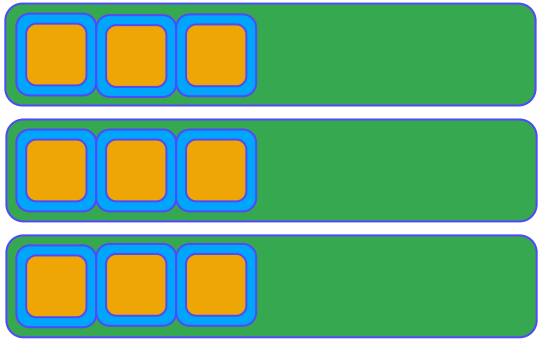

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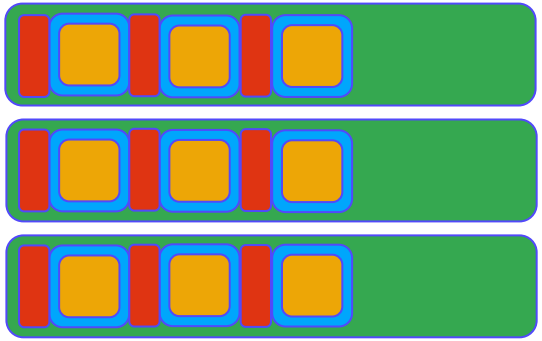

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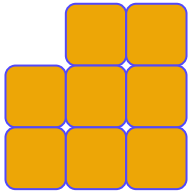

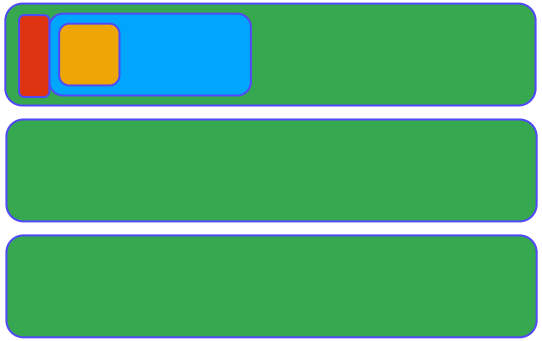

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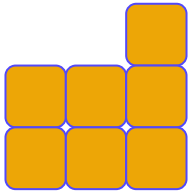

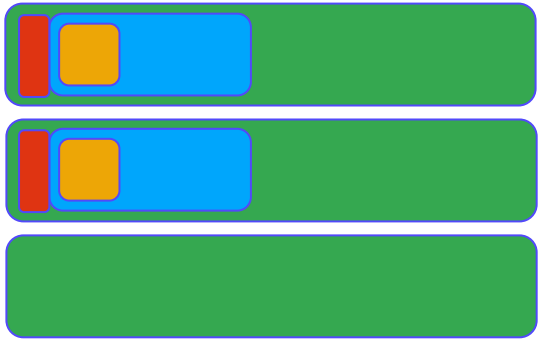

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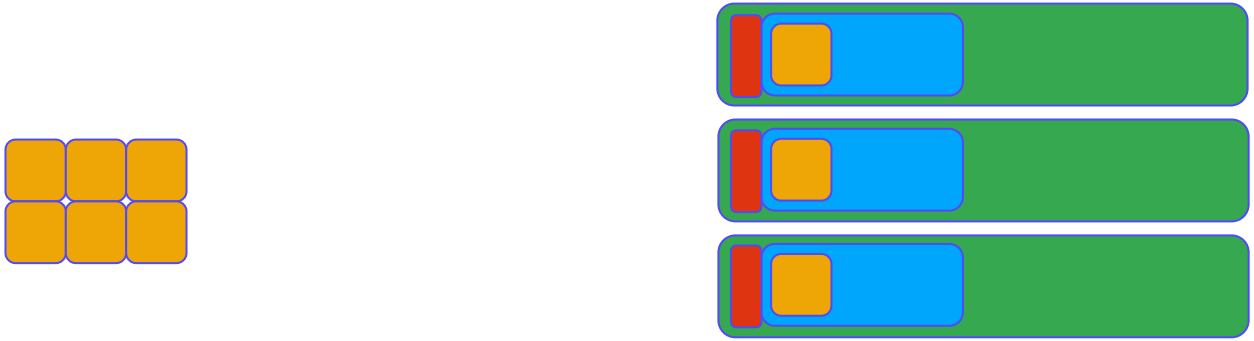

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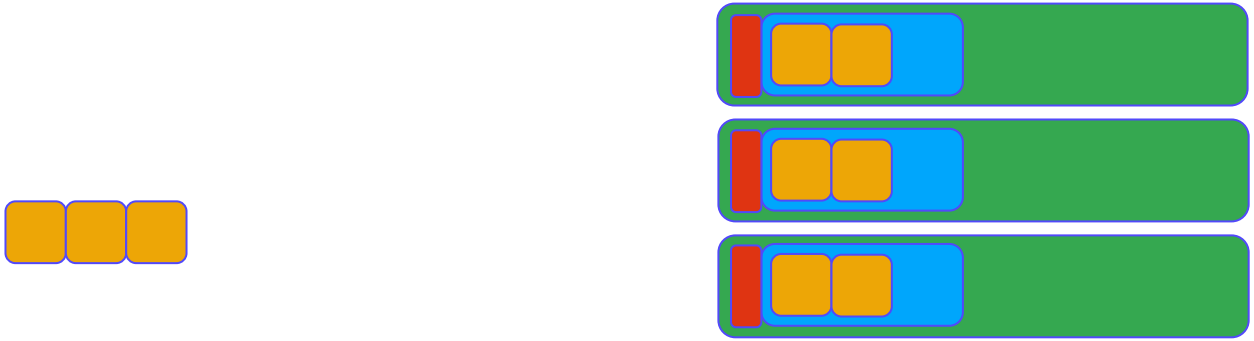

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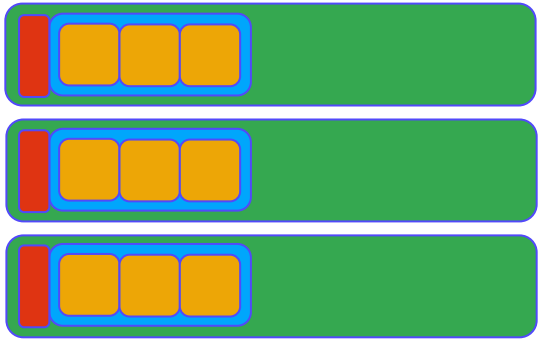

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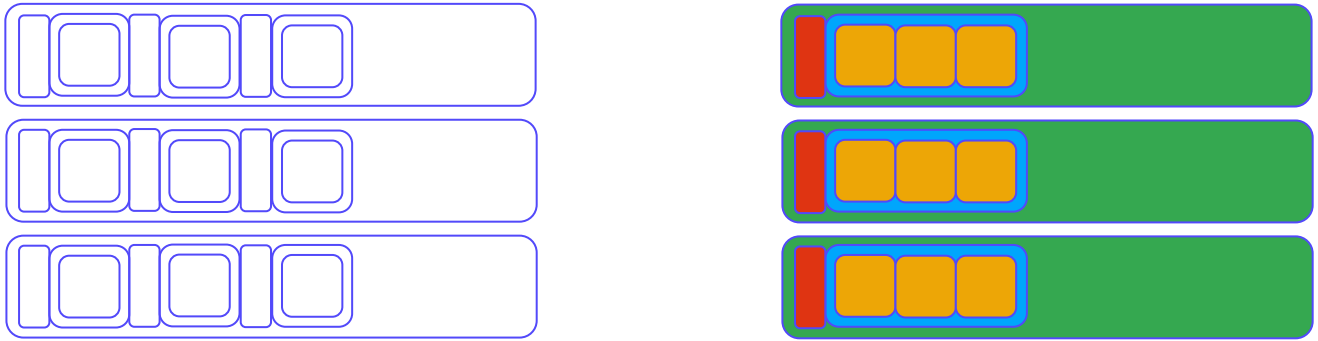

PERSISTENT KERNELS

```
for k in range(0, k_tiles):
  a = tl.load(a_ptrs)
  b = tl.load(b_ptrs)
  c = tl.dot(a, b, c)
  a_ptrs, b_ptrs = …
tl.store(c_ptrs, c)
```

PERSISTENT KERNELS

```
for tile_id in range(start, num_tiles, NUM_SMS):
  a_ptrs, b_ptrs = …
  c = tl.zeros()
  for k in range(0, k_tiles):
    a = tl.load(a_ptrs)
    b = tl.load(b_ptrs)
    c = tl.dot(a, b, c)
    a_ptrs, b_ptrs = …
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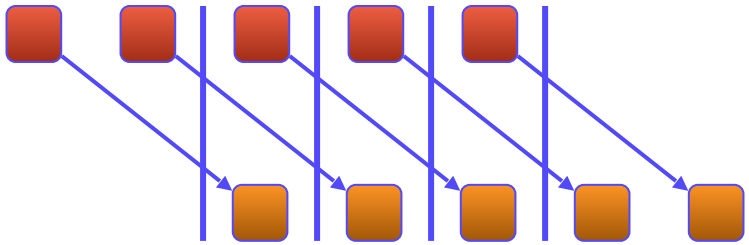
PUTTING THE TWO TOGETHER…



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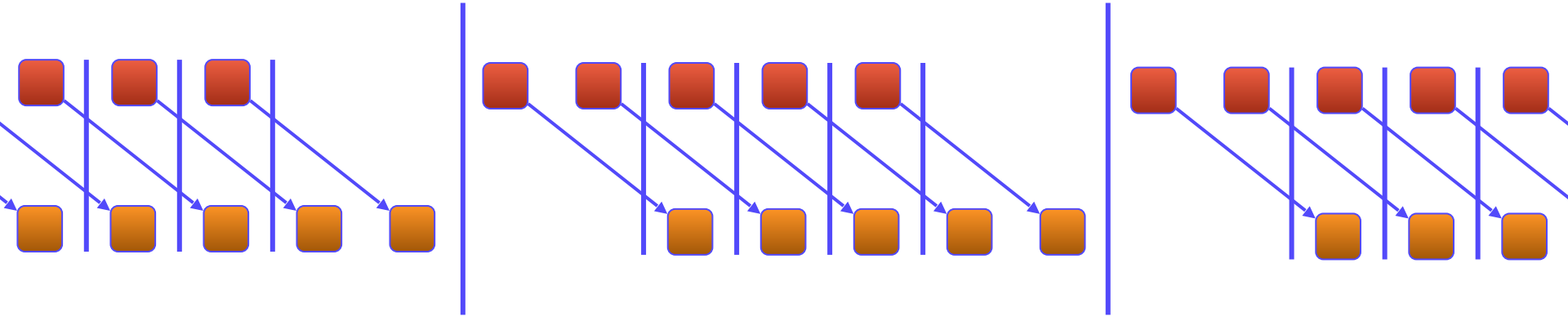

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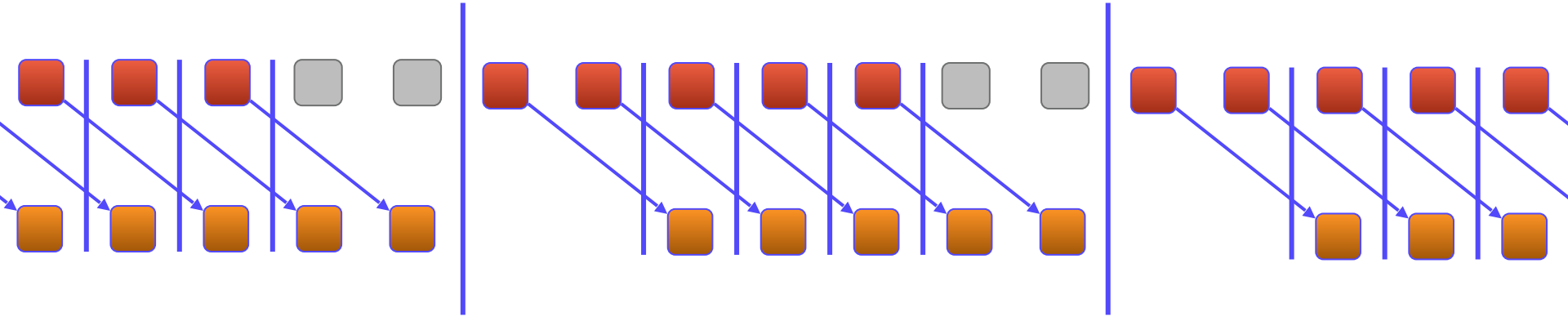

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for tile_id in range(start, num_tiles, NUM_SMS):
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for tile_id in range(start, num_tiles, NUM_SMS):
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    c = tl.dot(a, b, c)
    a_ptrs, b_ptrs = …
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```
for tile_id in range(start, tiles_per_SM * k_tiles):
```

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  a_ptrs, b_ptrs = …
  c = tl.zeros()
  for k in range(0, k_tiles):
    a = tl.load(a_ptrs)
    b = tl.load(b_ptrs)
    c = tl.dot(a, b, c)
    a_ptrs, b_ptrs = …
  tl.store(c_ptrs, c)
```

```
for tile_id in range(start, tiles_per_SM * k_tiles):
  tile_id, k = …
  if (k == 0):
    a_ptrs, b_ptrs = …
    c = tl.zeros()
```

PUTTING THE TWO TOGETHER… EFFICIENTLY

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for tile_id in range(start, num_tiles, NUM_SMS):
  a_ptrs, b_ptrs = …
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  for k in range(0, k_tiles):
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for tile_id in range(start, tiles_per_SM * k_tiles):
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  if (k == 0):
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```
for tile_id in range(start, tiles_per_SM * k_tiles):
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  if (k == 0):
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    c = tl.zeros()
  a_ptrs, b_ptrs = …
    c = tl.zeros()
  a = tl.load(a_ptrs)
  b = tl.load(b_ptrs)
  c = tl.dot(a, b, c)
  a_ptrs, b_ptrs = …
if (k == k_tiles-1):
    tl.store(c_ptrs, x)
```

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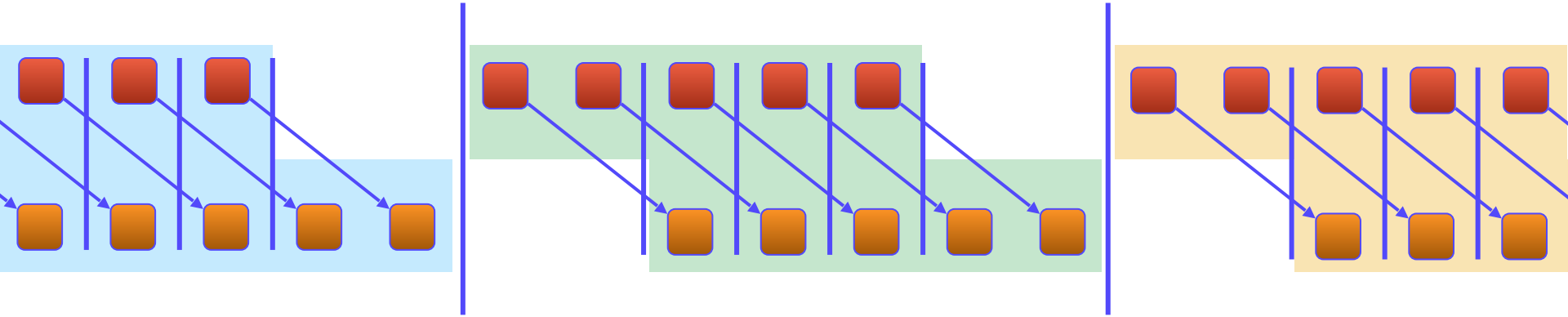

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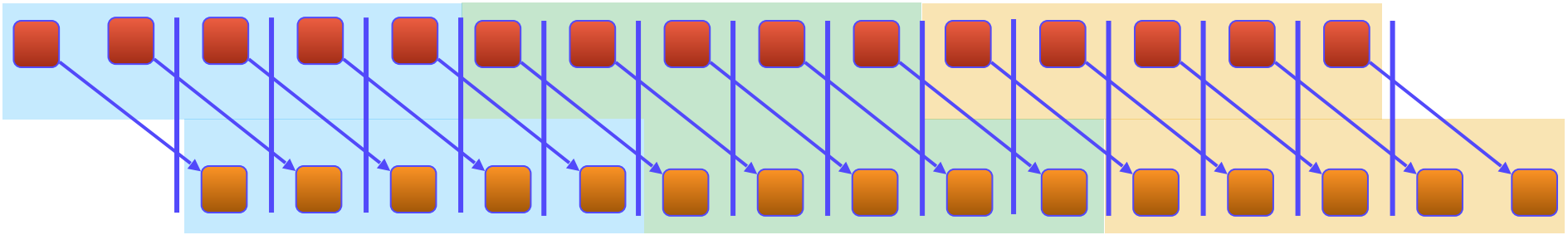

We do it not because it is easy…

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…But because we thought it would be easy.

Challenges

Hand-fused loops in matmul kernel, multitude of functional and performance problems

- Matmul optimized path not ready for branching in the main loop

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    - Axis Analysis 🪦

Challenges

Hand-fused loops in matmul kernel, multitude of functional and performance problems

- Matmul optimized path not ready for branching in the main loop
    - WGMMA pipelining 💀
    - Layout conversion optimizations 😵
    - Axis Analysis 🪦
- IfOp placement in the loop - major performance problem
    - Placed in the middle of the loop
    - Instruction scheduling off the window
    - Introduced CoarseSchedule, allowing for better control over ops placement

- **Final ingredient: TMA**
  - Less arithmetic in main loop because of HW-handled OOB

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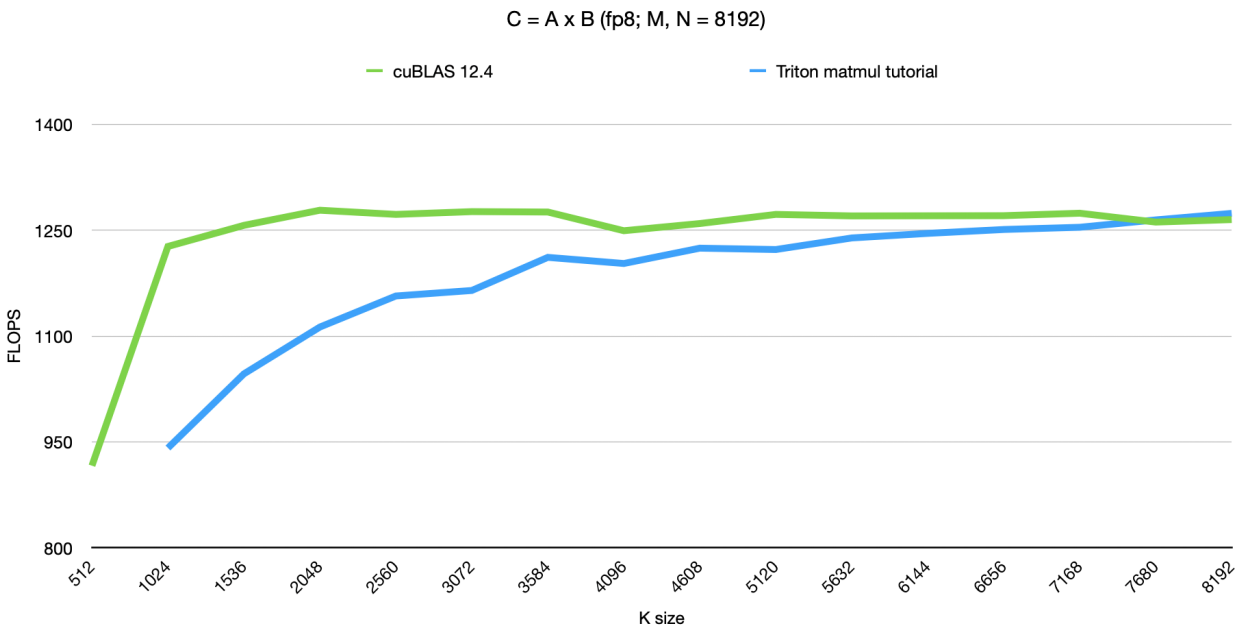
  - Less arithmetic in main loop because of HW-handled OOB
  - Async stores to global memory at the end of the tile

PUTTING THE TWO TOGETHER... EFFICIENTLY



* random A, B; 10000 warm-up, 1000 measurements avg; no fixed clocks; minimal startup overhead; measured with:
branch: `pawel/perf_data_collection`
cmd: `python 09-persistent-matmul.py --prec=fp8 --K_range 512 8192; proton-viewer -m "avg_time/us" matmul.hatchet`

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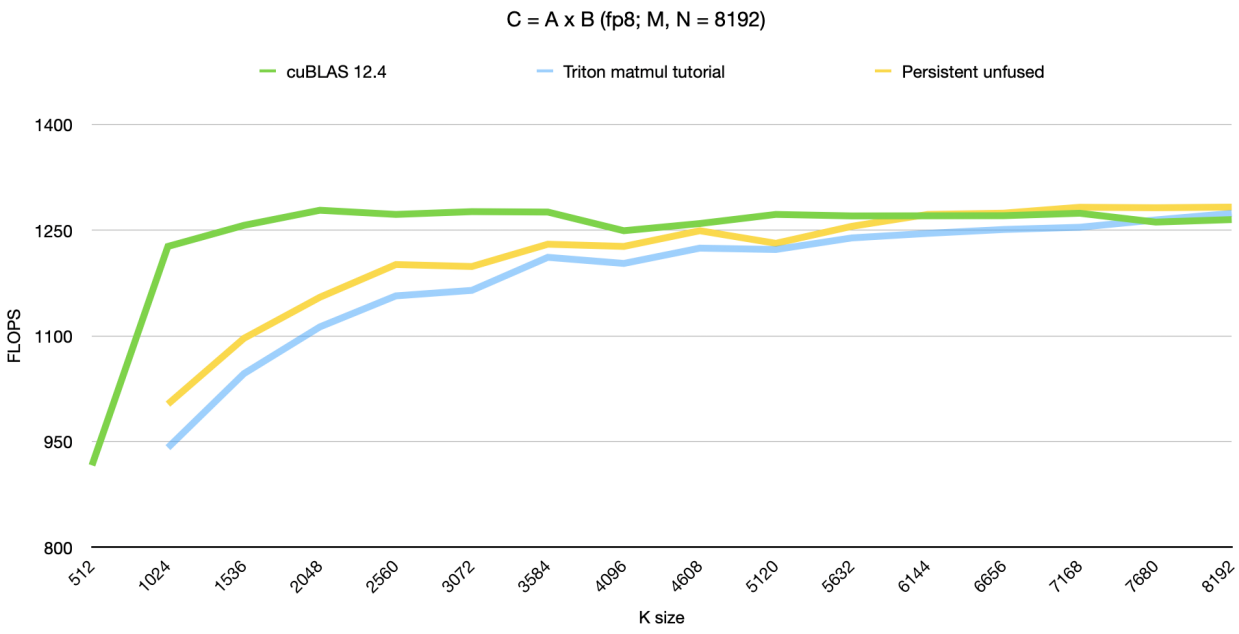

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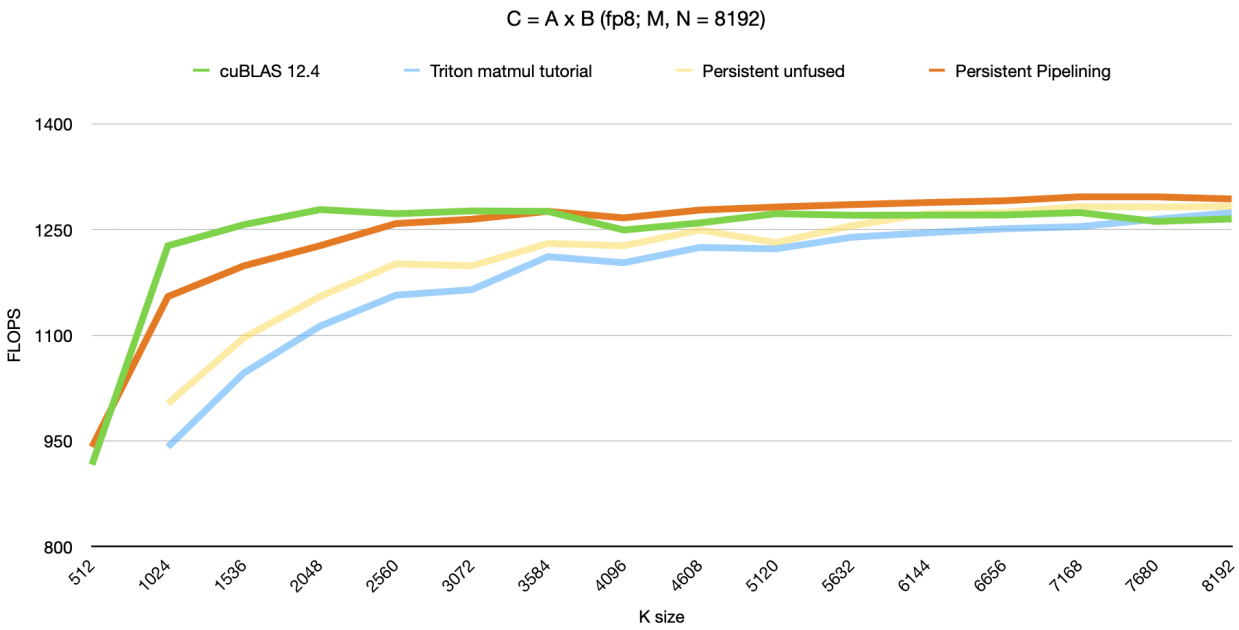

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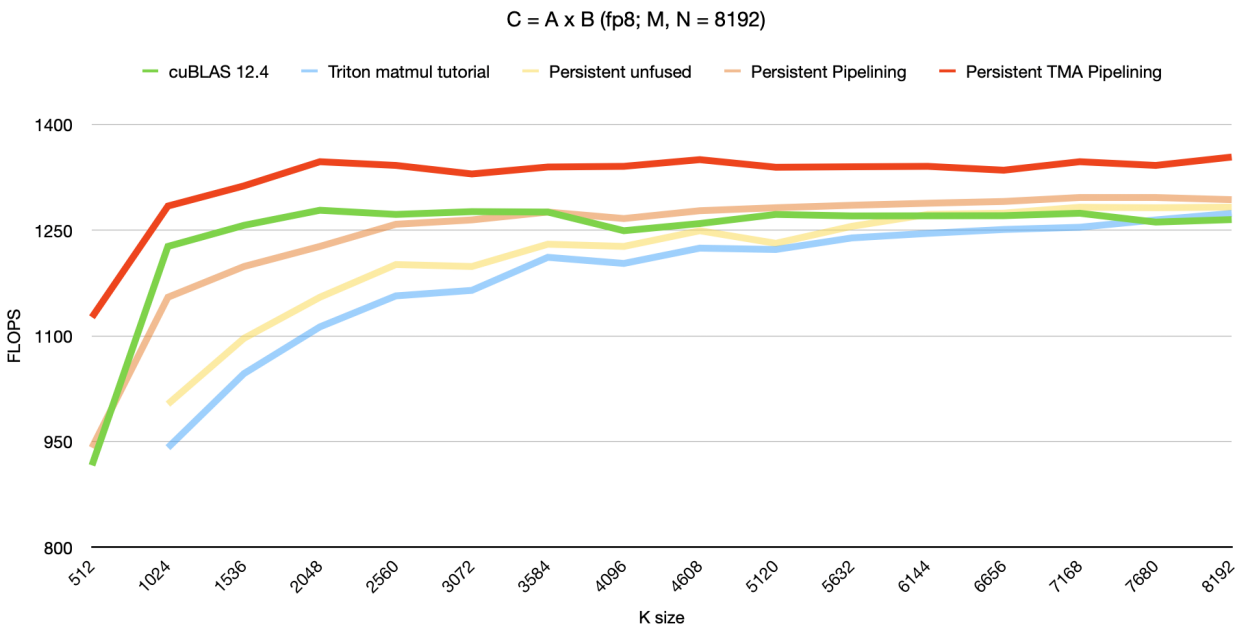

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Further Work

- TMA descriptor passing via grid constant by Elliot Gorokhovsky (Meta)
- TMA descriptor on-device creation and update by Peter Bell (OpenAI)
- Pipeliner refactoring and support for multiple schedules led by Manman Ren (Meta)

- Further further work
    a. Layering schedules
    b. Epilogue tiling
    c. Automatic loop fusion
    d. …

Thank you!