OpenCL Library of Stream Memory Components Targeting FPGAs

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Introduction

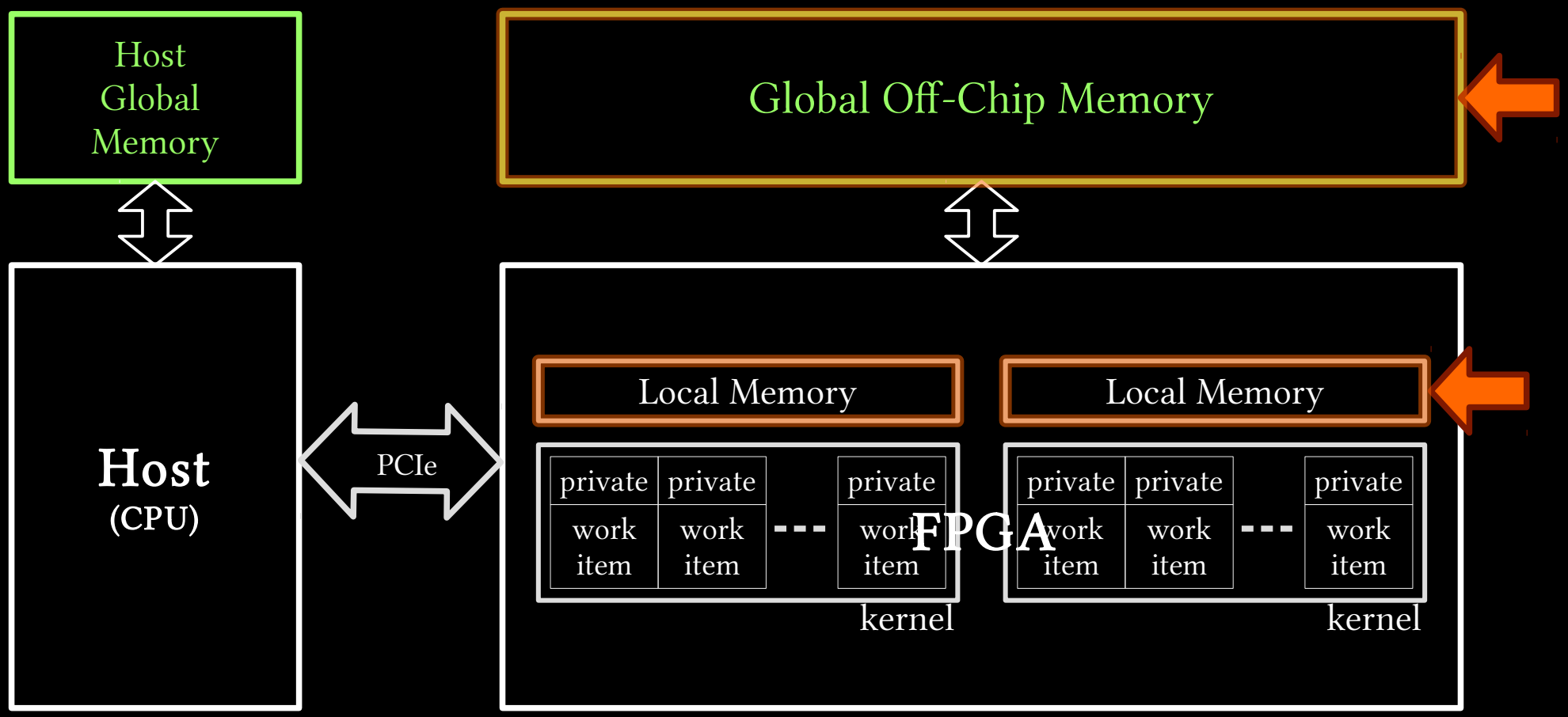
- Exciting time for FPGAs
  - Data center deployment
  - Stream applications
- Improvement in programming environment
  - OpenCL compilers for FPGAs
  - Xilinx SDAccel
- In a nutshell
  - A library of stream memory components
  - SDAccel environment

Introduction

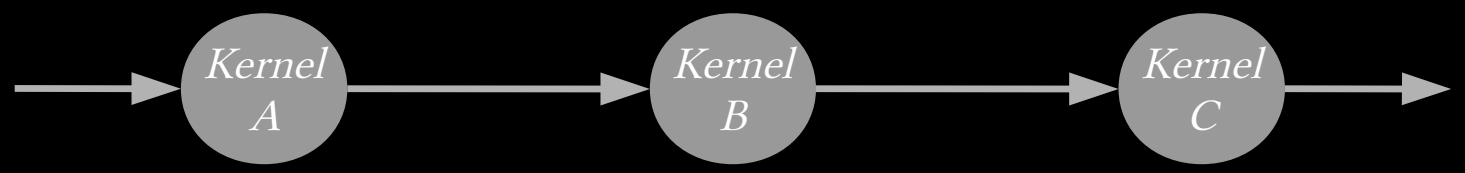
- *Stream applications on FPGAs*
  - Parallel processing pipelines & compute intensive
  - Use lots of memory
  - High throughput
  - *Steady and predictable data accesses*

- ***Library of commonly used memory building blocks***
  - *Stencil, tile, transpose*
  - *Pre-optimized data movement and buffering*
  - *Highly configurable*

OpenCL Memory Model

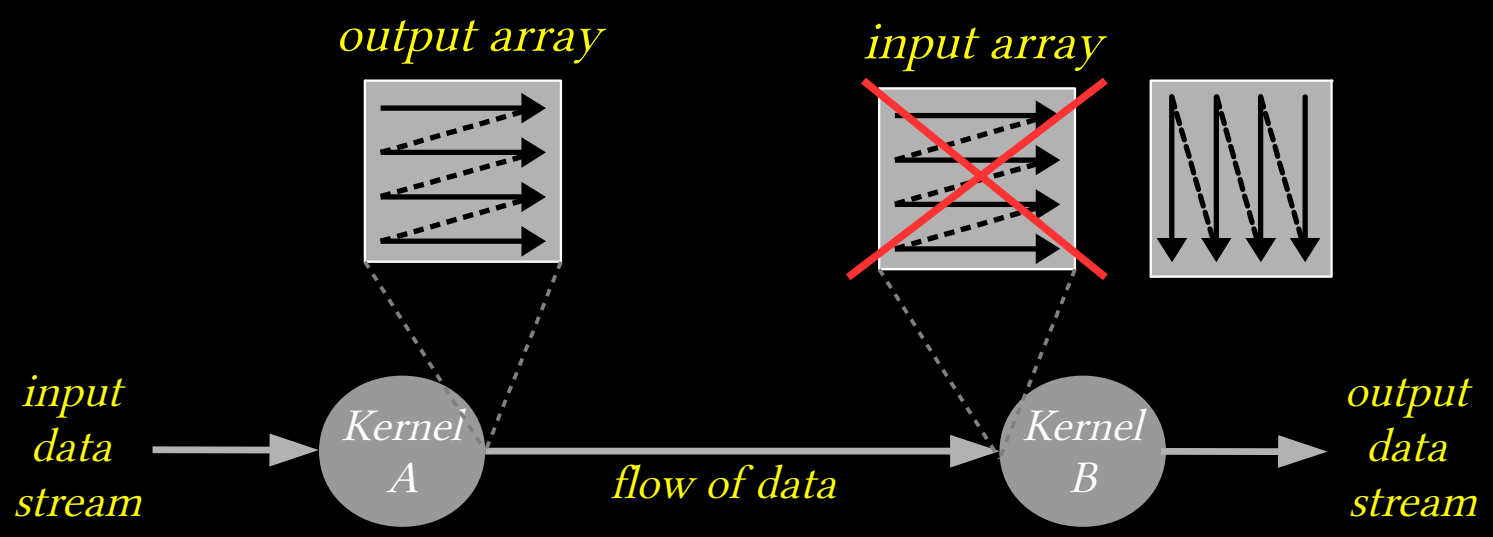


Stream Applications

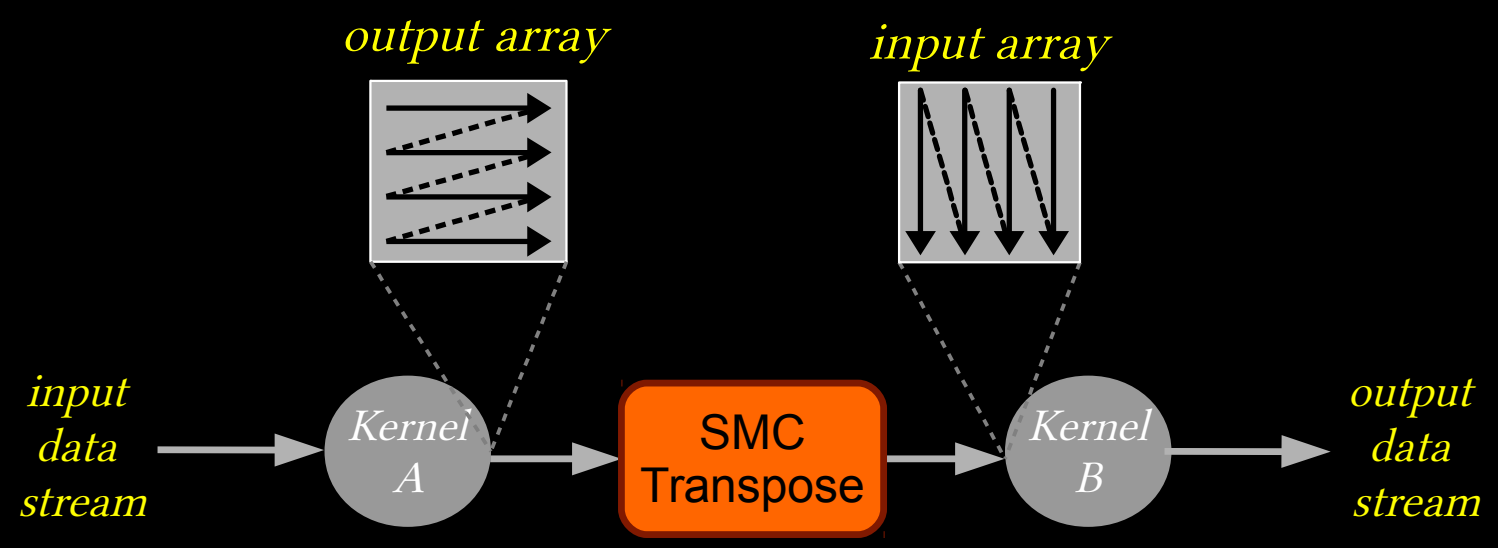


- DFG – Data Flow Graph
  - *Nodes* – compute kernels
  - *Edges* – flow of data

Stream Applications



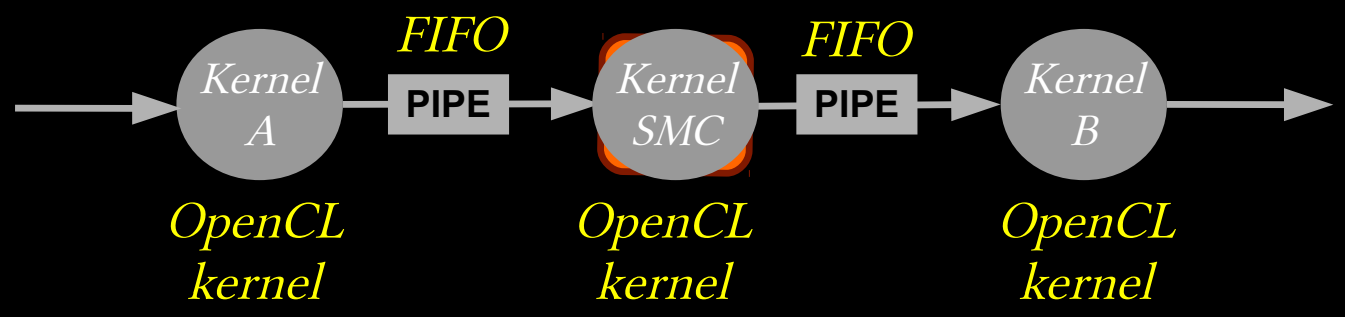
Stream Applications



- SMC – Stream Memory Component
  - Buffers and re-formats data

Stream Memory Components

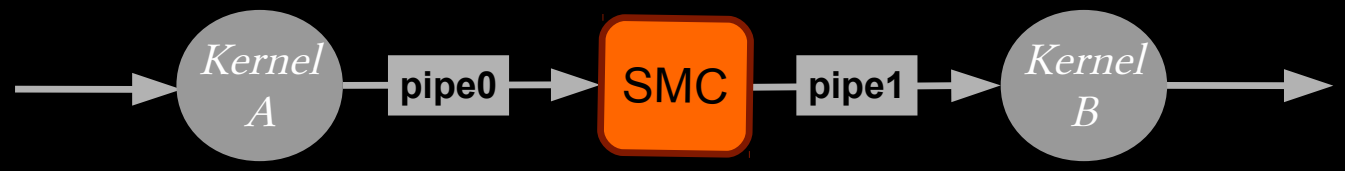
- OpenCL -



- SMC is implemented as an OpenCL kernel
- OpenCL ***pipe object***
  - a FIFO implemented in BRAMs

Stream Memory Components

- OpenCL -



Host Code

```
0. #include "smc.h"
1.
2. cl_mem pipe0;
3. cl_mem pipe1;
4.
5. clEnqueueNDRangeKernel(KernelA, ...);
6.
7. smcEnqueueTranspose(p0, p1, p2, ...);
8.
9. clEnqueueNDRangeKernel(KernelB, ...);
```

include the SMC header

create two pipes

launch Kernel A

launch SMC

launch Kernel B

The SMC Library

The SMC Library

- User Configurations -

1) *Common data transformations*

2) *Input/output configuration*

3) *Memory resources vs. performance trade-off*

The SMC Library

- User Configurations -

1) ***Common data transformations***

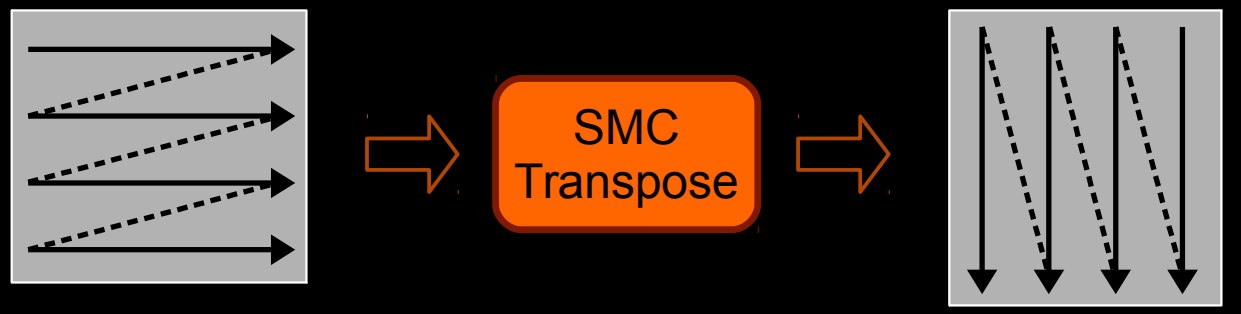
2) *Input/output configuration*

3) *Memory resources vs. performance trade-off*

Stream Memory Components

- Common Data Transformations -

1. **Transpose**
2.
3.

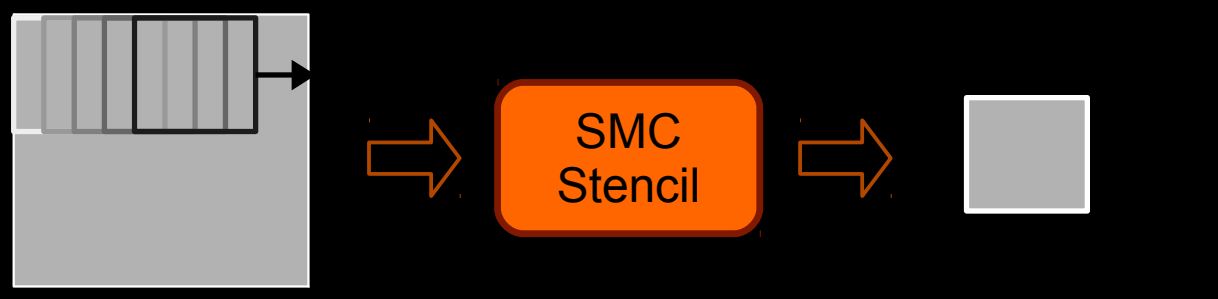


frame in *frame out*

Stream Memory Components

- Common Data Transformations -

1. Transpose
2. **Stencil**
3.

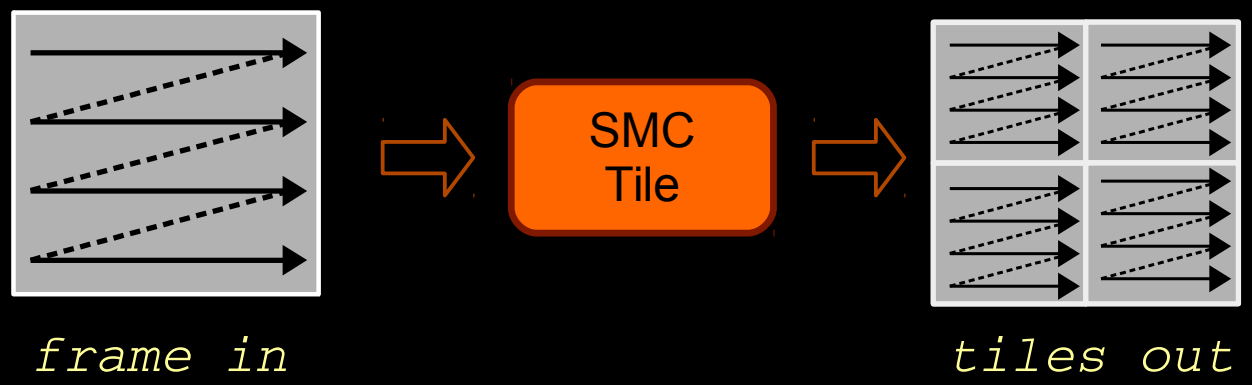


frame in *window out*

Stream Memory Components

- Common Data Transformations -

1. Transpose
2. Stencil
3. **Tile**



The SMC Library

- User Configurations -

1) *Common data transformations*

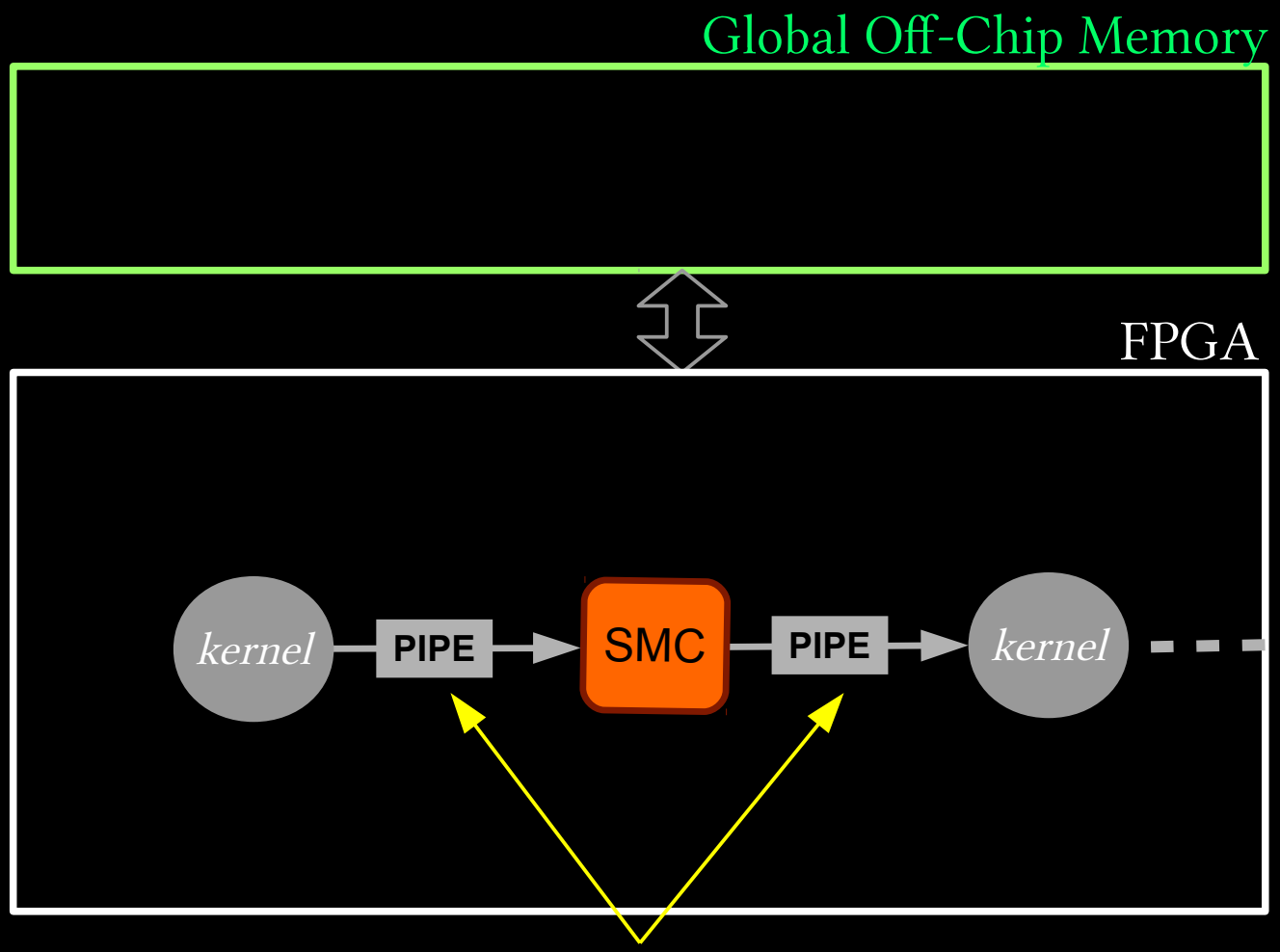
2) ***Input/output configuration***

3) *Memory resources vs. performance trade-off*

Stream Memory Components

- Input & Output Configuration -

1. **PIPE to PIPE**
2.
3.
4.

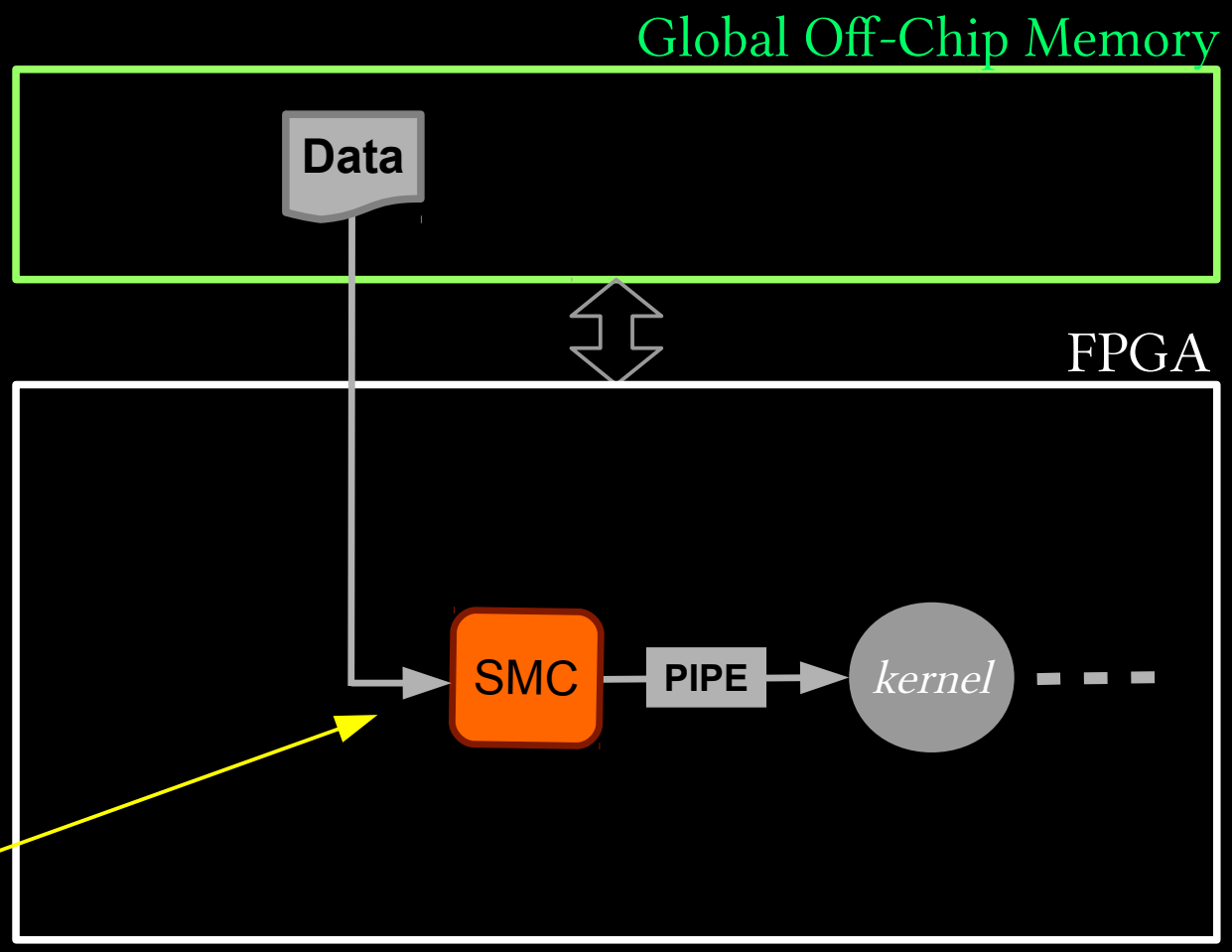


- low latency read/write
- BRAMs
- random access

Stream Memory Components

- Input & Output Configuration -

1. PIPE to PIPE
2. **GLOBAL to PIPE**
3.
4.

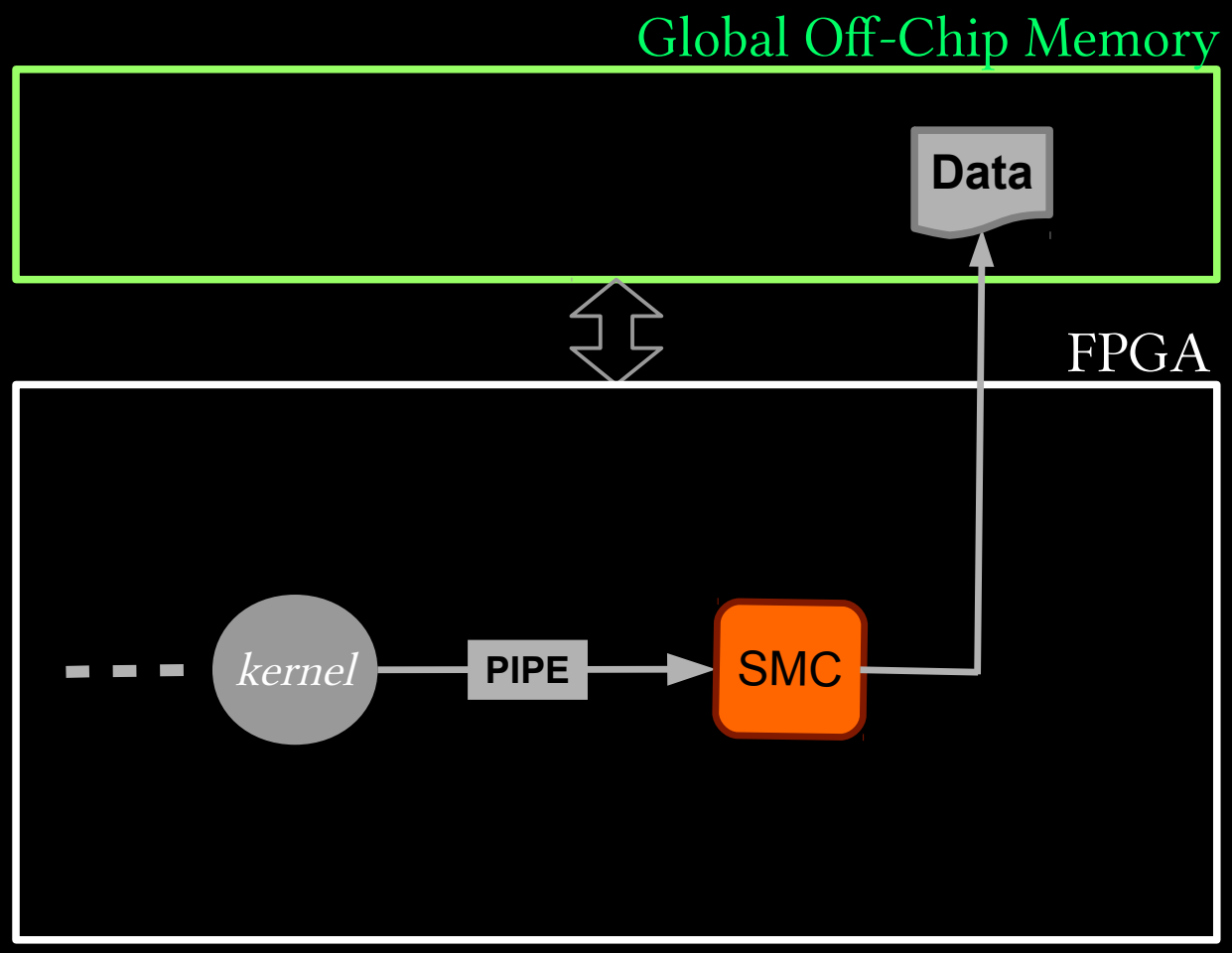


- high access latency
- data access pattern sensitive
- burst read/writes maximize performance

Stream Memory Components

- Input & Output Configuration -

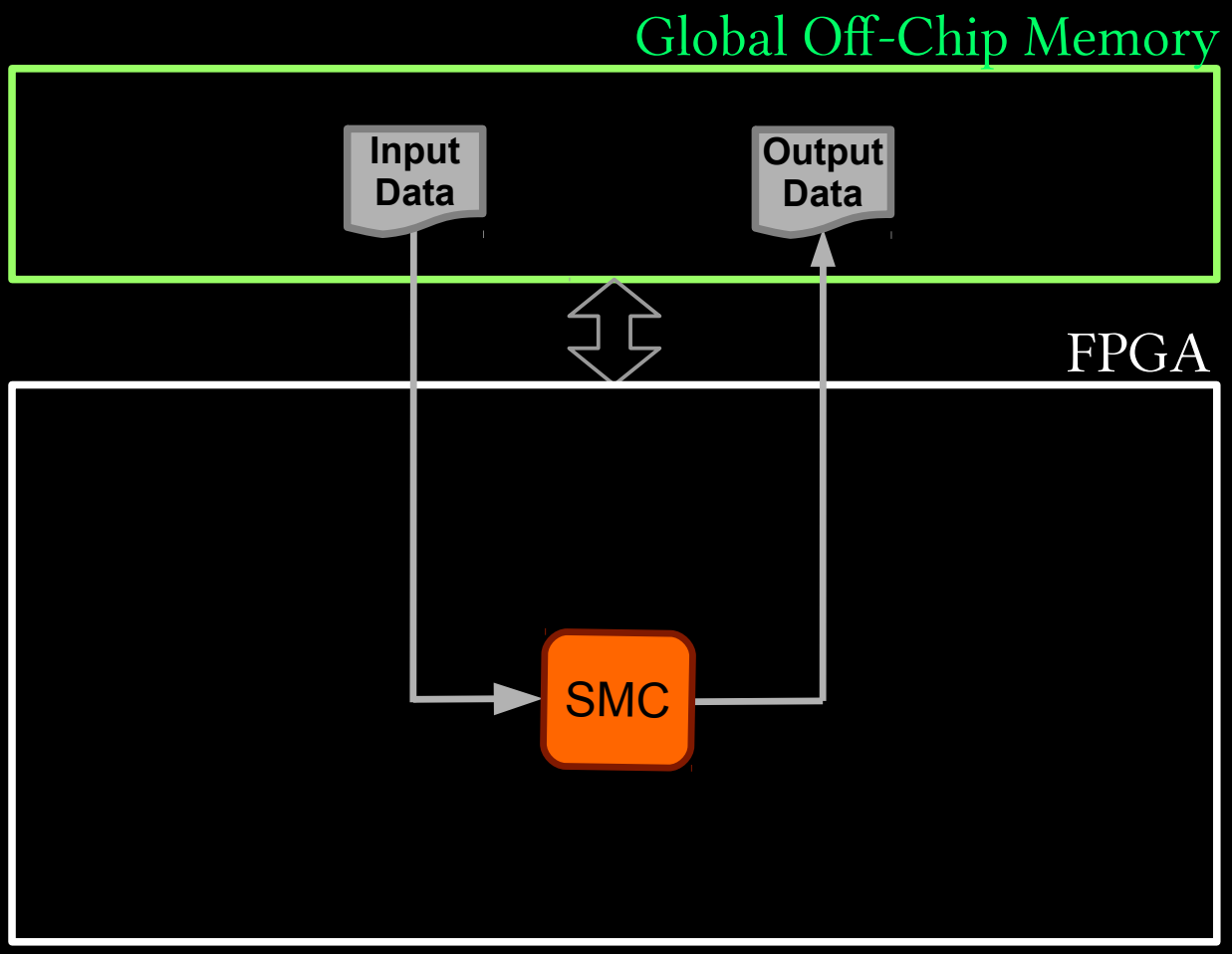
1. PIPE to PIPE
2. GLOBAL to PIPE
3. **PIPE to GLOBAL**
4.



Stream Memory Components

- Input & Output Configuration -

1. PIPE to PIPE
2. GLOBAL to PIPE
3. PIPE to GLOBAL
4. **GLOBAL to GLOBAL**



The SMC Library

- User Configurations -

1) *Common data transformations*

2) *Input/output configuration*

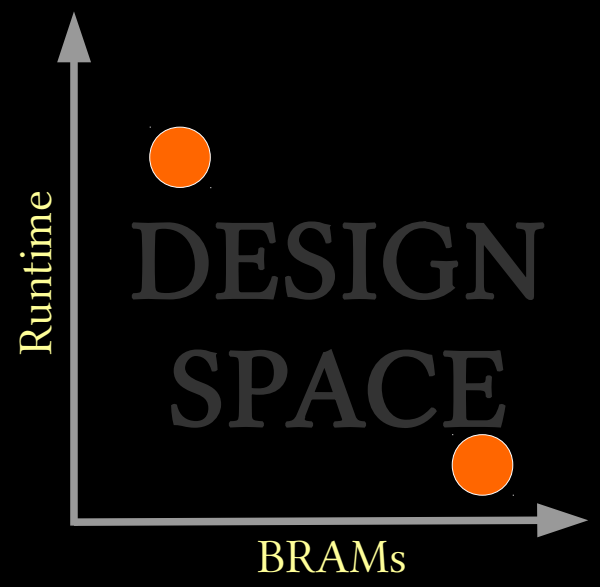
3) ***Memory resources vs. performance trade-off***

Stream Memory Components

- Memory Resources vs. Performance -

- Tradeoff between BRAMs used and performance of the SMC

- Two optimization approaches:
  1) *Adjusting the size of burst accesses from global memory*
  2) *Mapping to heterogeneous OpenCL memory regions*



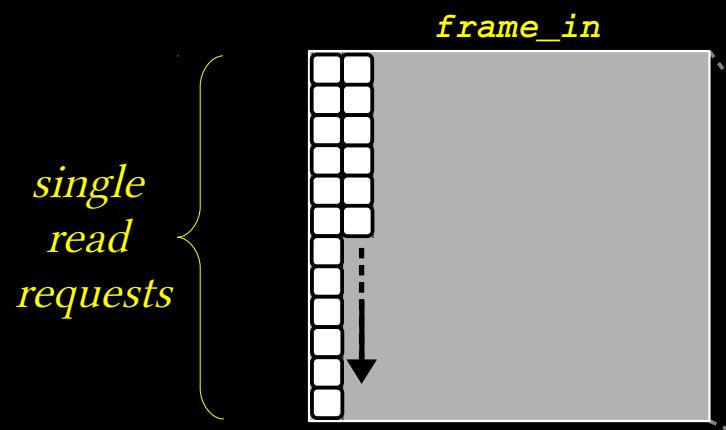
Host Code

```
smcEnqueueTranspose(...,128,...);
```

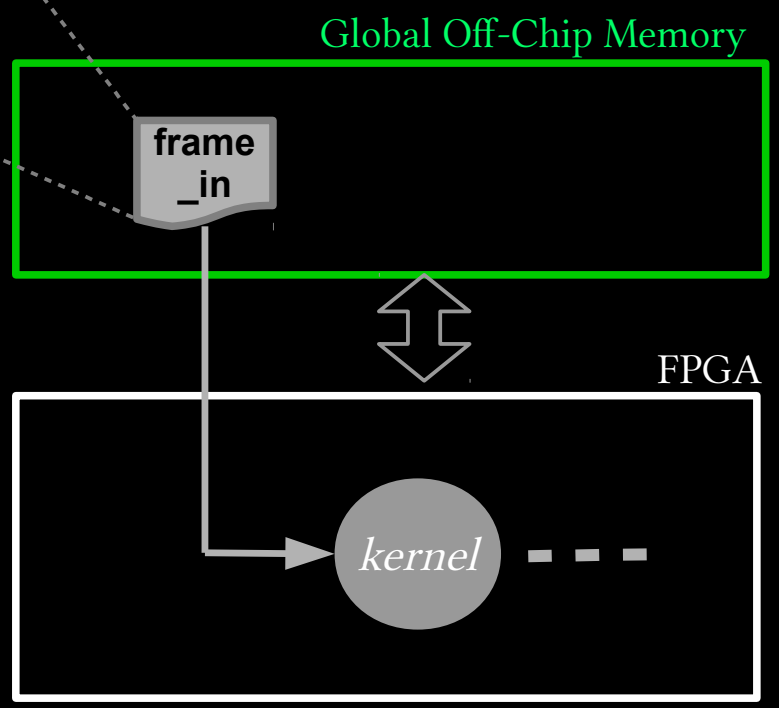
# of BRAMs

Stream Memory Components

- Memory Resources vs. Performance -



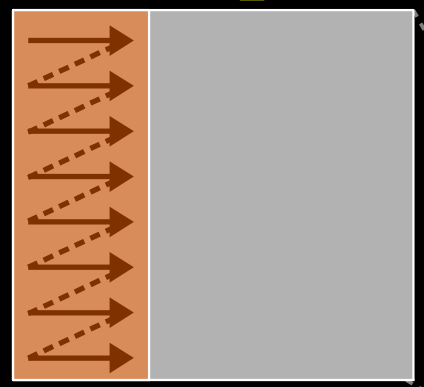

```
__kernel myKernel( __global int* frame_in
                   __global int* frame_out)

  for x=0 to H {
    for y=0 to W {

      frame_out[x][y] = frame_in[x][y] + C;

    }
  }
```



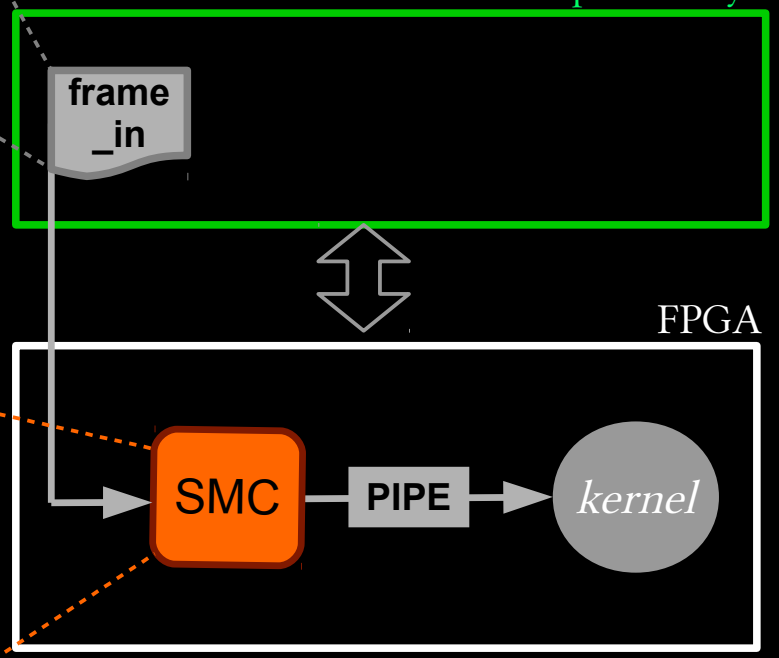
Stream Memory Components

- Memory Resources vs. Performance -

- 512-bit words
- burst reads

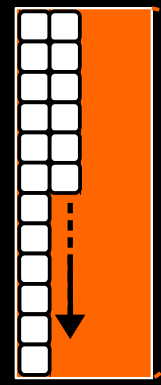



```
__kernel myKernel( __global int* output)

  for x=0 to H {
    for y=0 to W {

      read_pipe(smc_transpose, &temp);
      frame_out[x][y] = temp + C;

    }
  }
```



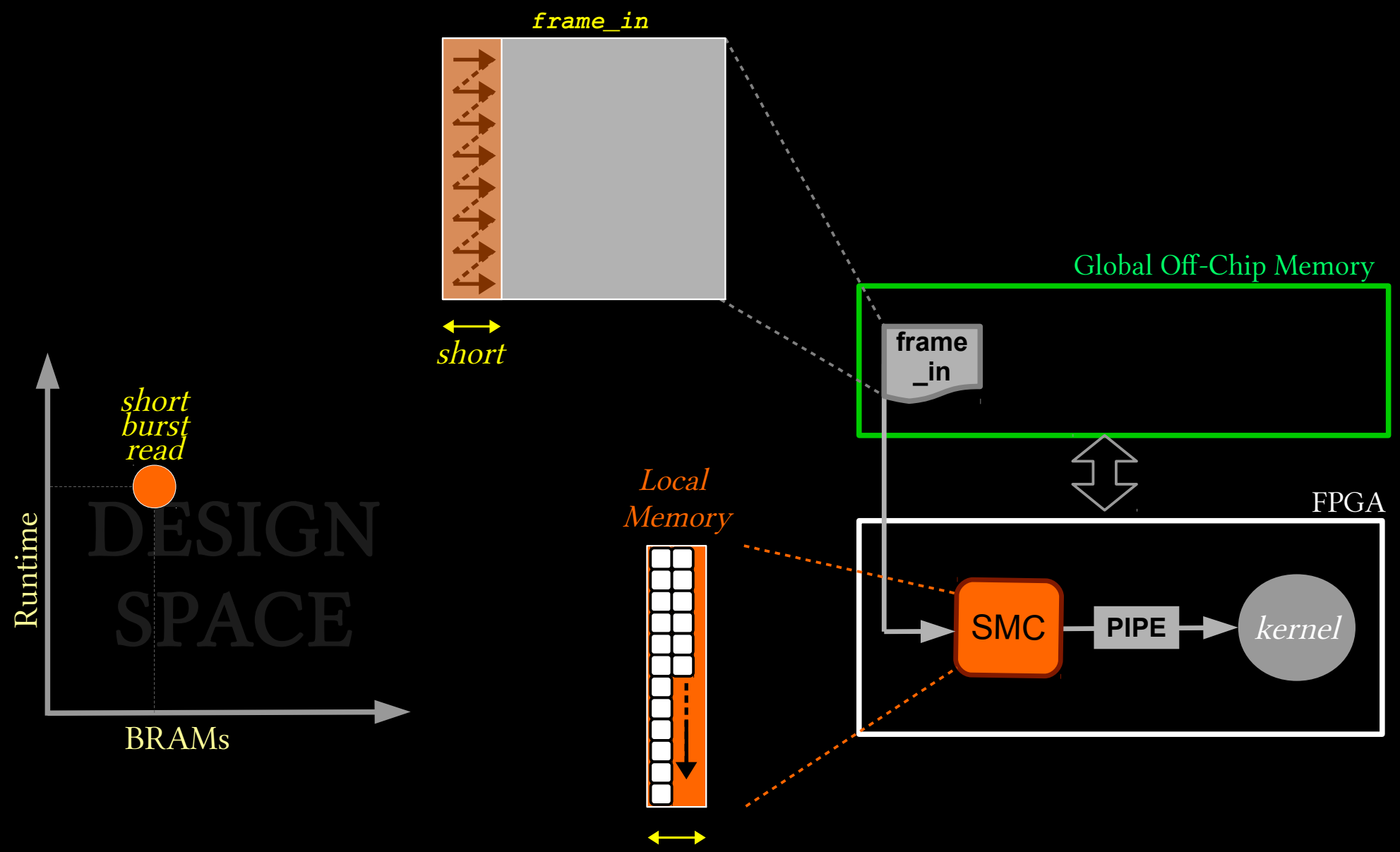
Local Memory

low-latency random access



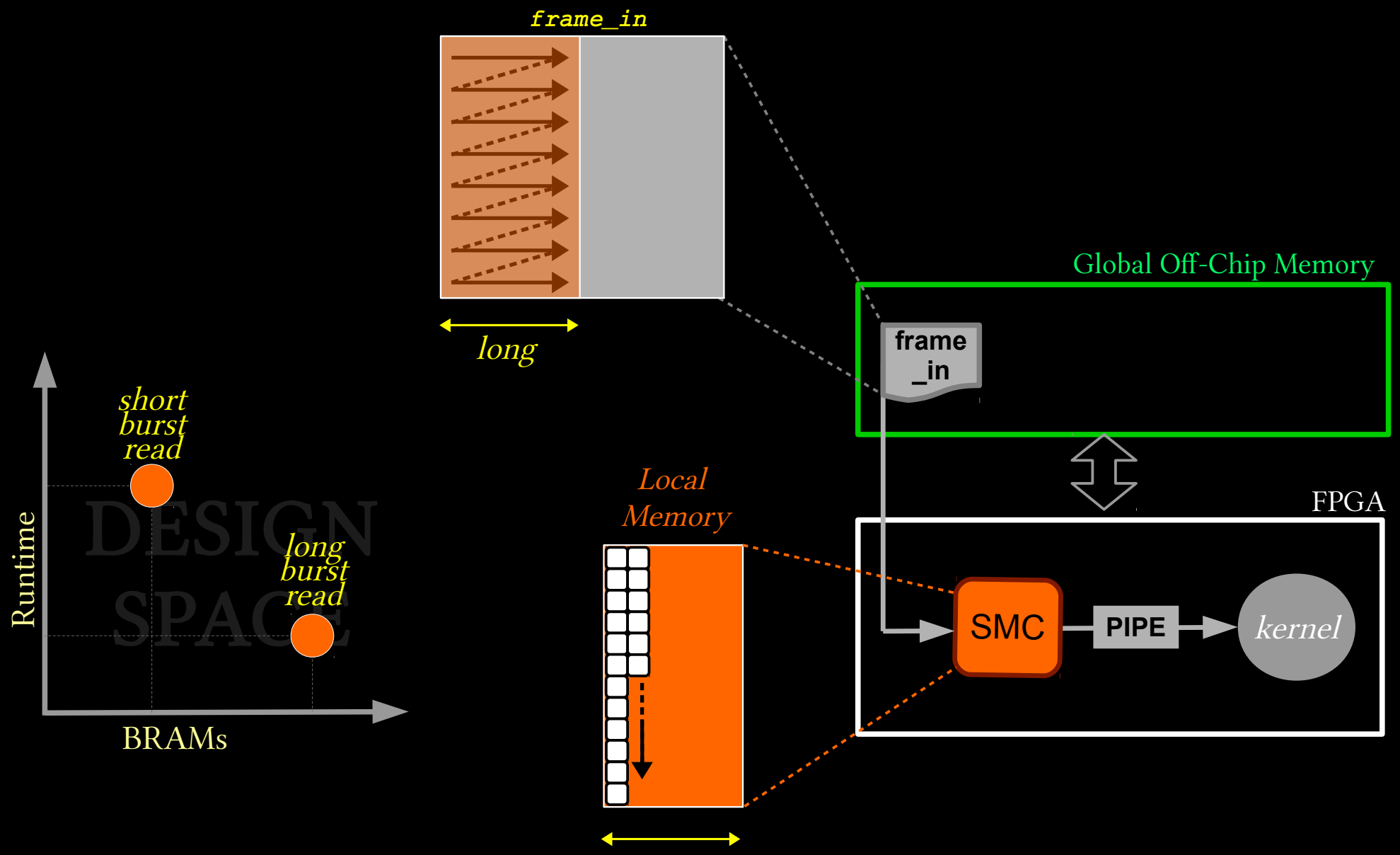
Stream Memory Components

- Memory Resources vs. Performance -



Stream Memory Components

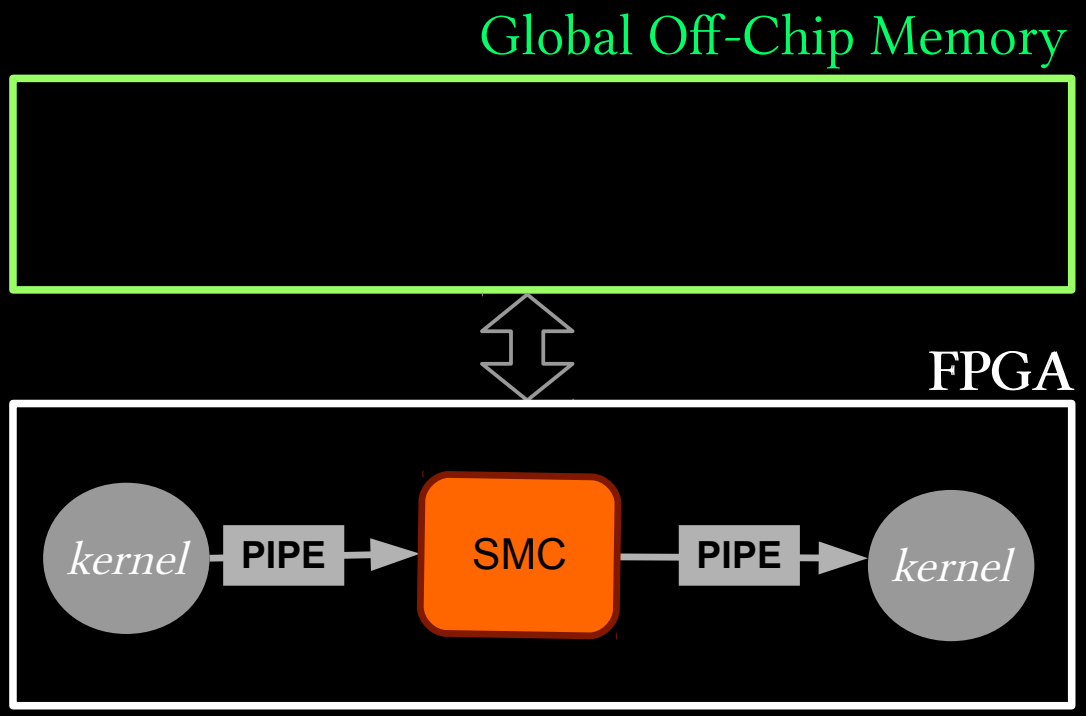
- Memory Resources vs. Performance -



Stream Memory Components

- Memory Resources vs. Performance -

- SMC needs to buffer data
- Buffering size:
  - SMC type
  - data size
  - performance



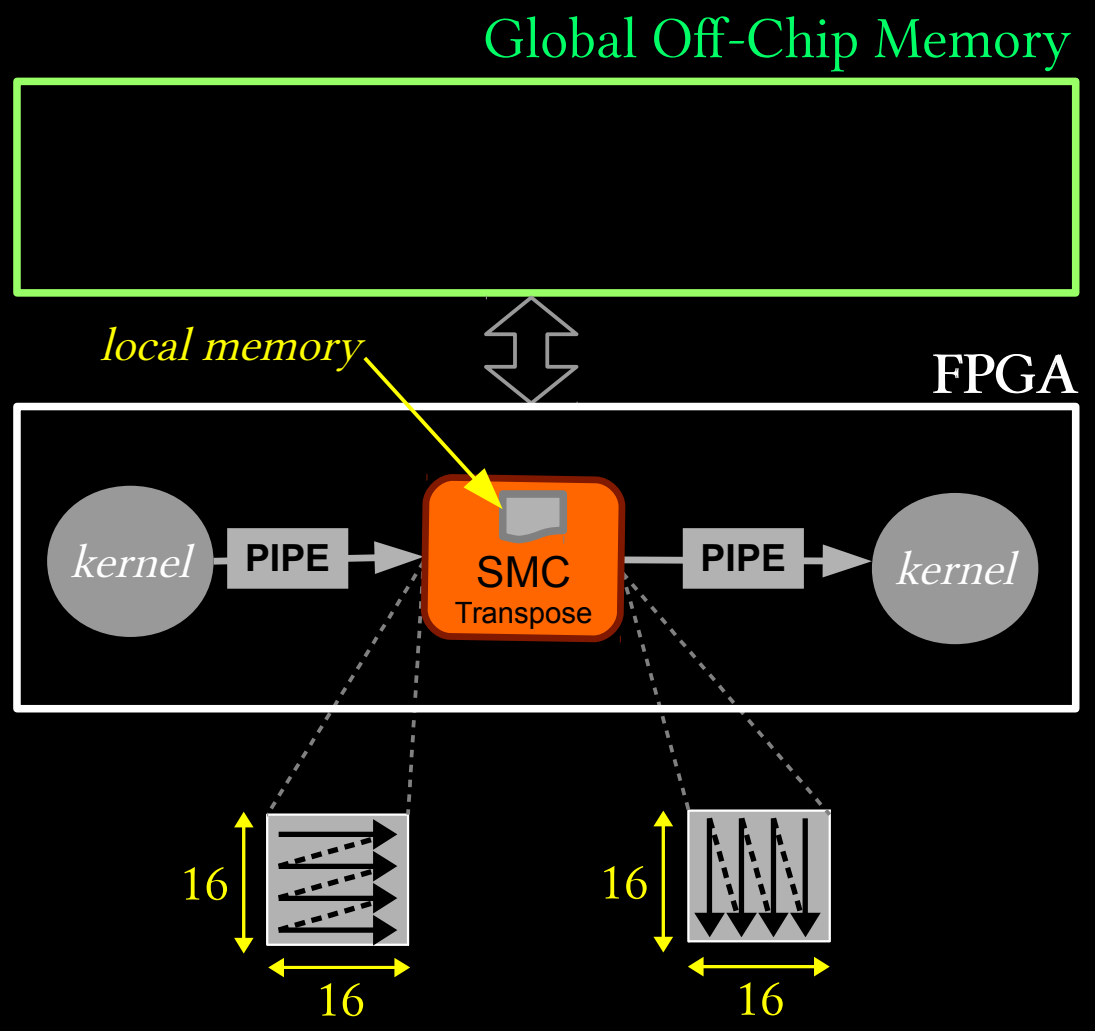
Stream Memory Components

- Memory Resources vs. Performance -

Example:

- SMC transpose
- PIPE to PIPE config
- Data size: 16x16

256 words
1 BRAM of storage



Host Code

```
smcEnqueueTranspose(...,16,16,...);
```

data size

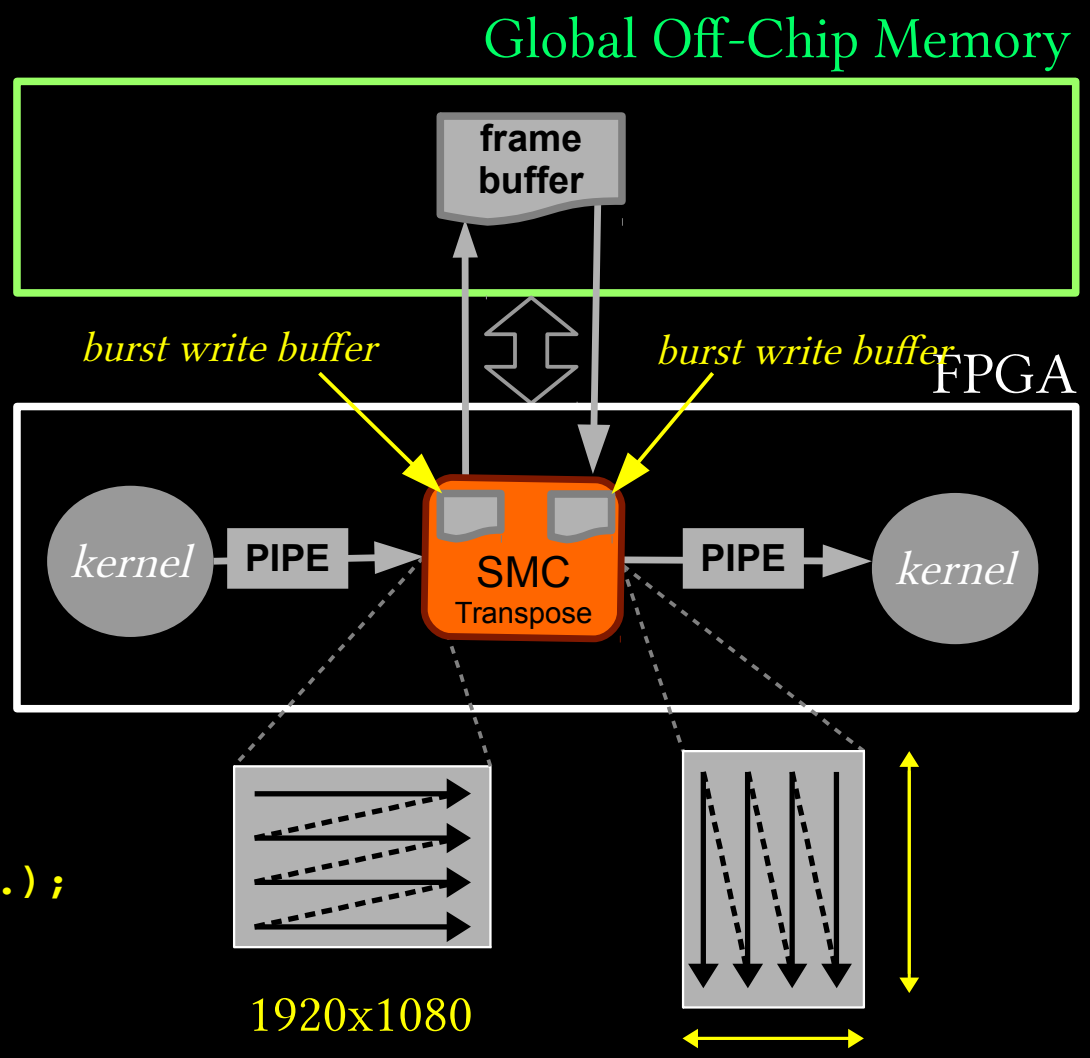
Stream Memory Components

- Memory Resources vs. Performance -

Example:

- SMC transpose
- PIPE to PIPE config
- Data size: HD video frame

2,073,600 words
3048 BRAM of storage



Host Code

```
smcEnqueueTranspose(...,1920,1080,...);
```

data size

Experimental Evaluation

- Memory Resources vs. Performance -

Transpose

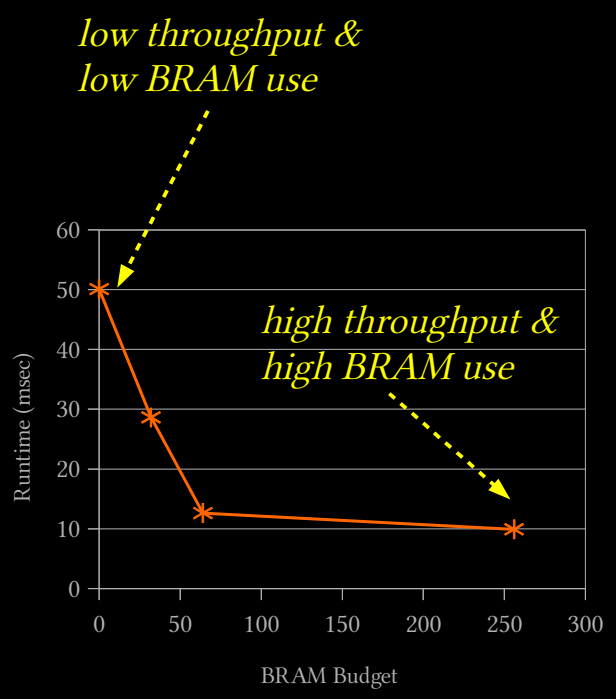
- single transpose SMC
- GLOBAL to GLOBAL
- 32-bit, 1024x1024 array

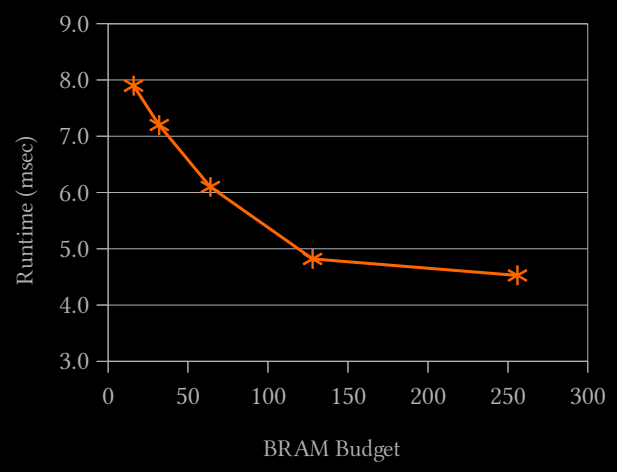
Video Watermarking

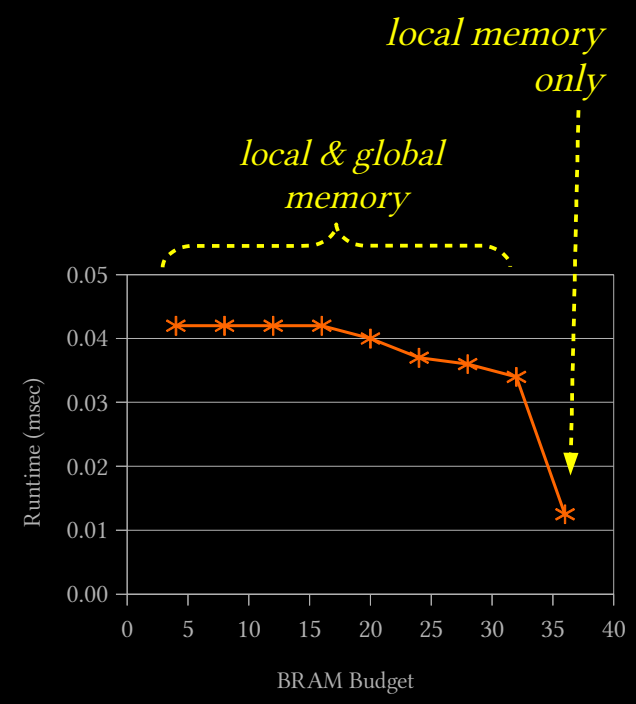
- four tile SMCs
- GLOBAL to PIPE
- PIPE to GLOBAL
- 32-bit, 1024x1024 array

FIR Filter

- single stencil SMCs
- PIPE to PIPE
- 9x9 FIR filter
- 32bit data







Experimental Evaluation

- Naive vs. SMC Optimized Performance -

Benchmark	Run-Time (msec)	BRAMs	DSPs	FF	LUTs	Run-Time (msec)	BRAMs	DSPs	FF	LUTs	Speedup
Video Watermarking	**15.4**	9	0	1,923	2,148	**4.82**	128	128	8,390	6,478	**3.2**
Matrix Multiply	**48.3**	0	4	2,380	2,834	**54**	96	4	13,477	29,799	**8.9**

Thank you