Investigating Data Layout Transformations in Chapel

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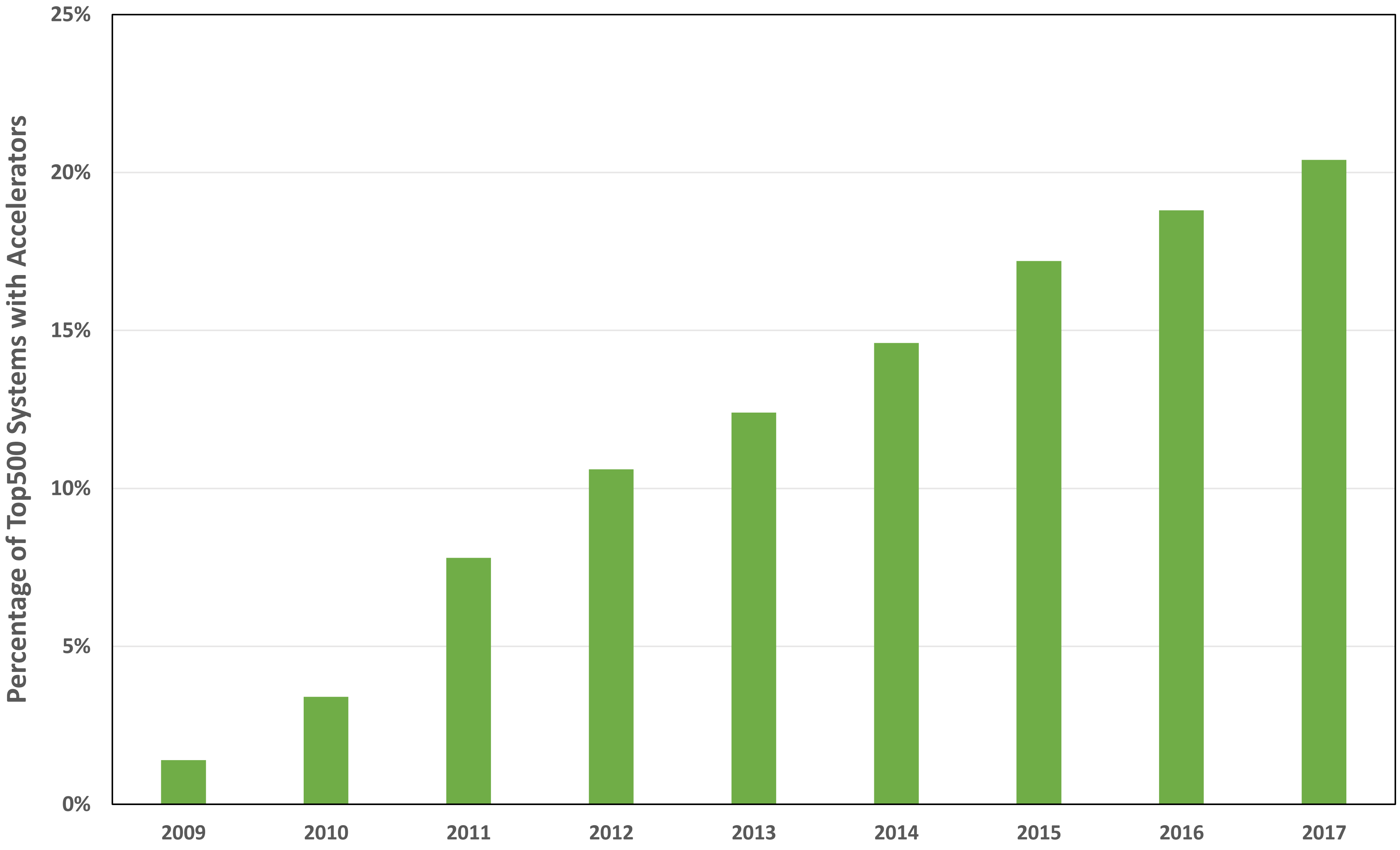
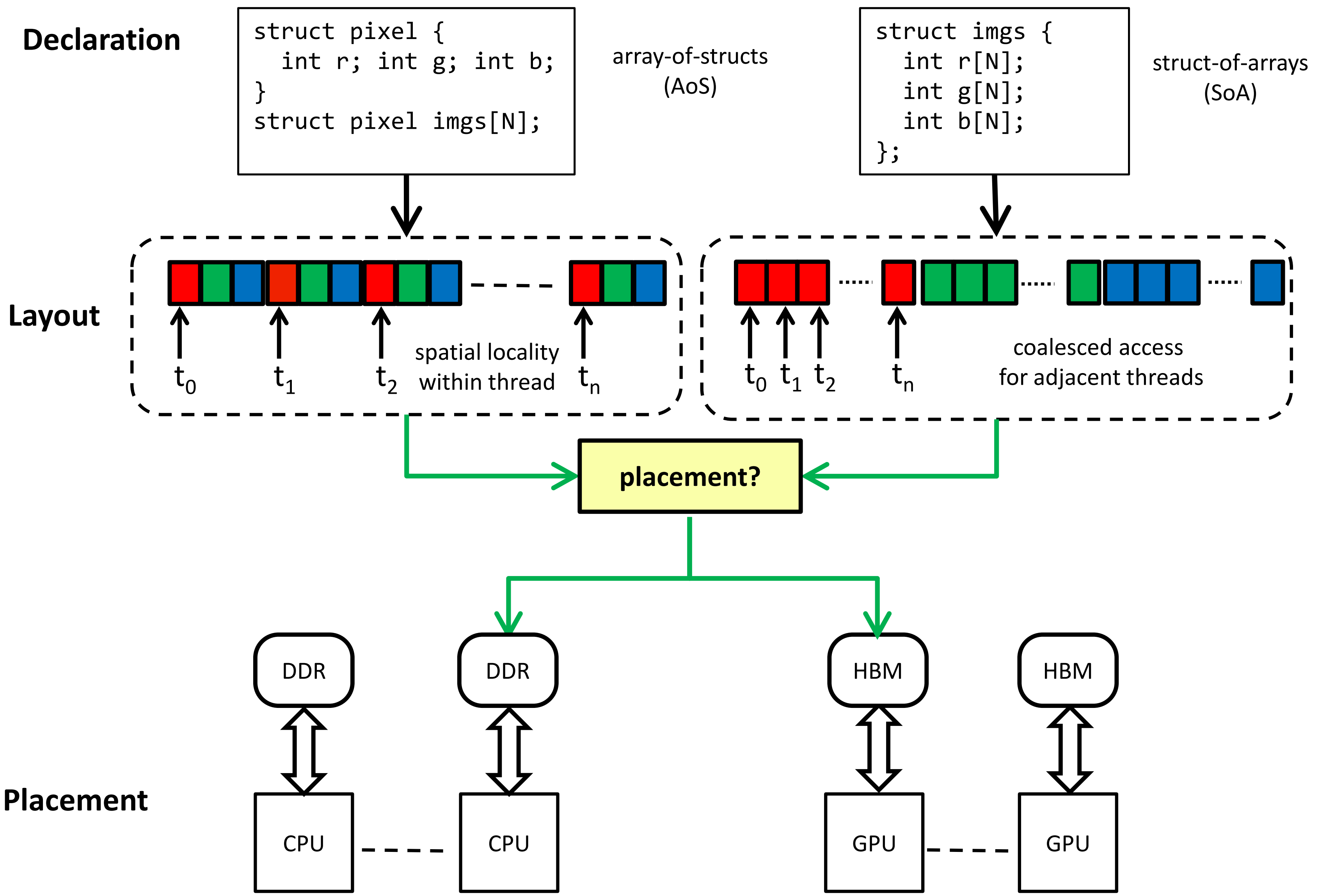
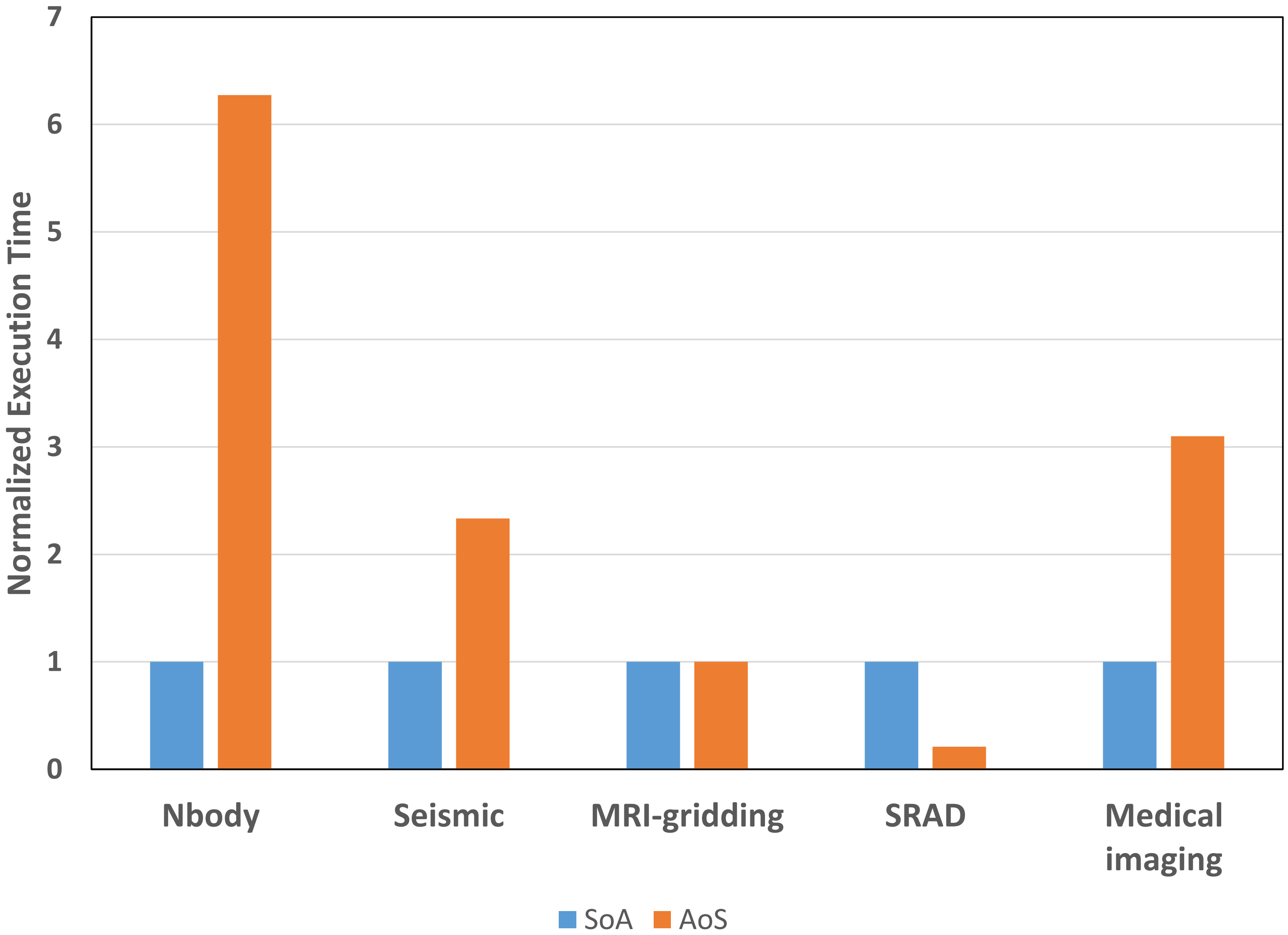
EMERGENCE OF HETEROGENEOUS NODE ARCHITECTURES



THE DATA ORGANIZATION PROBLEM



PERFORMANCE IMPACT OF DATA LAYOUT



OTHER EXAMPLES OF DATA LAYOUT ISSUES

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- Access to non-contiguous array locations

```
void conv2D(float** A, float** B) {
  int i, j;
  float c11, c12, c13;
  c11 = +0.2;  c21 = +0.5;  c31 = -0.8;
  ...
  for (i = 1; i < NI - 1; ++i) {
    for (j = 1; j < NJ - 1; ++j) {
      B[i][j] = c11 * A[i - 1][j - 1] +
                c12 * A[i][j - 1]  +
                c13 * A[i + 1][j - 1]
      ...
}
```

Serial C

```
__global__ void conv2D(float *A, float *B) {

  int i = blockIdx.x * blockDim.x + threadIdx.x;
  float c11, c12, c13;
  c11 = +0.2;  c21 = +0.5;  c31 = -0.8;
  int j;
  for (j = 0; j < NJ - 1; j++ )
   B[i * NJ + j] = c11 * A[(i-1) * NJ + (j-1)] +
                   c12 * A[i * NJ + (j-1)] +
                   c13 * A[(i+1) * NJ + (j-1)]
   ...
}
```

Parallel CUDA

OTHER EXAMPLES OF DATA LAYOUT ISSUES

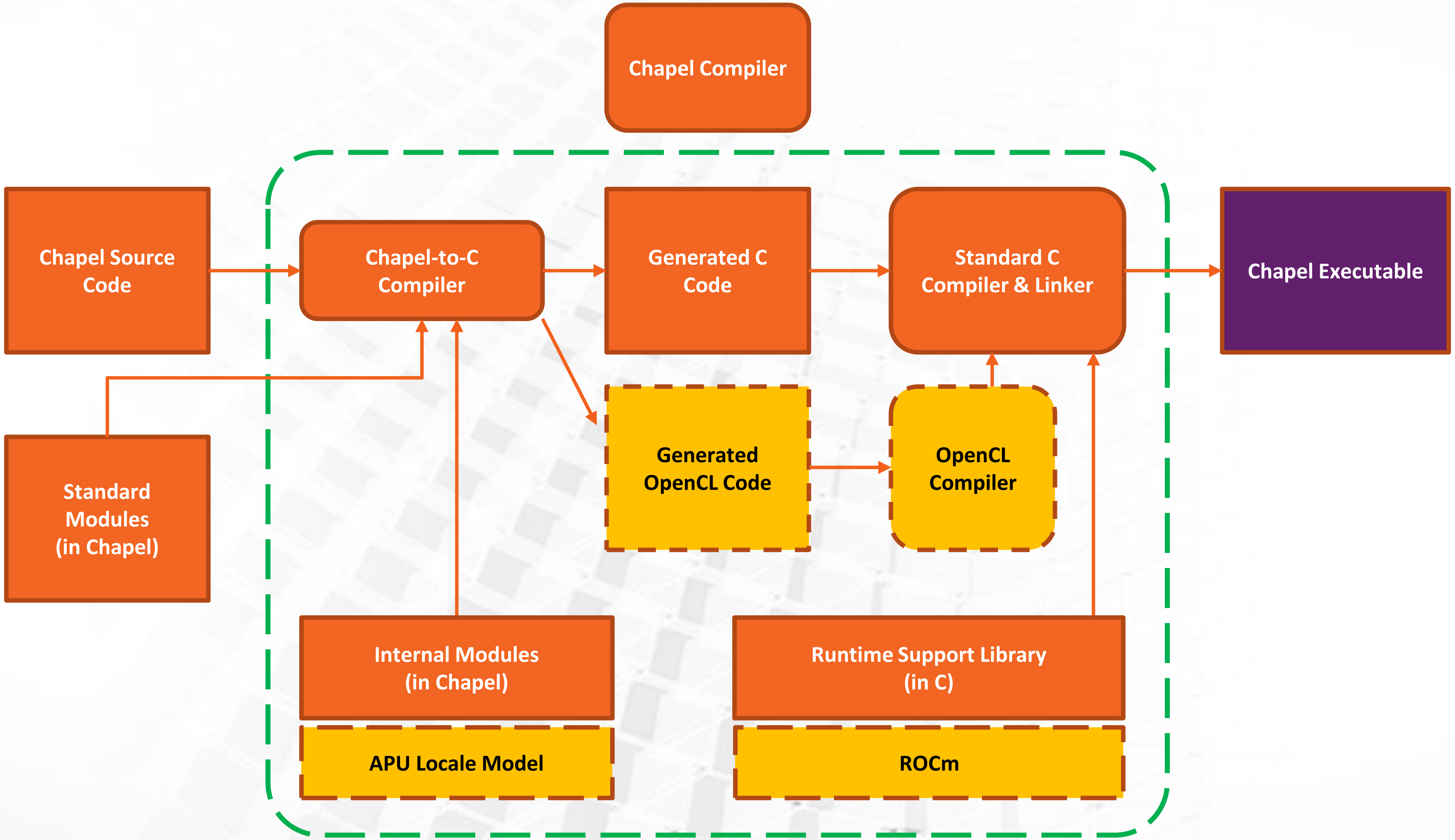
- Sparse Data Access
  - Non-unit stride access to data structure

```
mb_sad_calc(unsigned short *blk_sad,
            unsigned short *frame, ... ) {
    int tx = f(threadIdx.x)
    int ty = f(threadIdx.x);
    ...
    int cur_o = f(tx, ty, width, …);
    ...
    for(int y = 0; y < 4; y++)
     for (int x = 0; x < 4; x++)
       sad4x4 += abs(ty, tx, x, y, ..)
              - frame[cur_o + y * width + x]);
}
```

THIS WORK

- Investigates mechanisms for data layout transformations in Chapel
- Leverages Chapel-specific features
  - Index sets
  - Domain maps
- Explores both automatic and semi-automatic transformations
  - No change to the core language (as yet)

CHAPEL COMPILATION FRAMEWORK WITH GPU EXTENSIONS



DATA LAYOUT TRANSFORMATION 1: COLUMN-MAJOR TRANSFORMATION

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```
var domRowMajor : domain(2) = {rows, cols};
var domColMajor : domain(2) dmapped ColMajor() = {rows, cols};

var A : [domRowMajor] real ;
var B : [domColMajor] real ;

for i in rows {
   for j in cols {
       A[i,j] = 17.0; // accessed as row-major
       B[i,j] = 0.0; // accessed as col-major
   }
}
```

- Implemented ColMajor as a domain map
- Modeled after DefaultRectangular module
  - Constructor redefinition: remap index sets
  - Adjustment of dsiAccess() methods

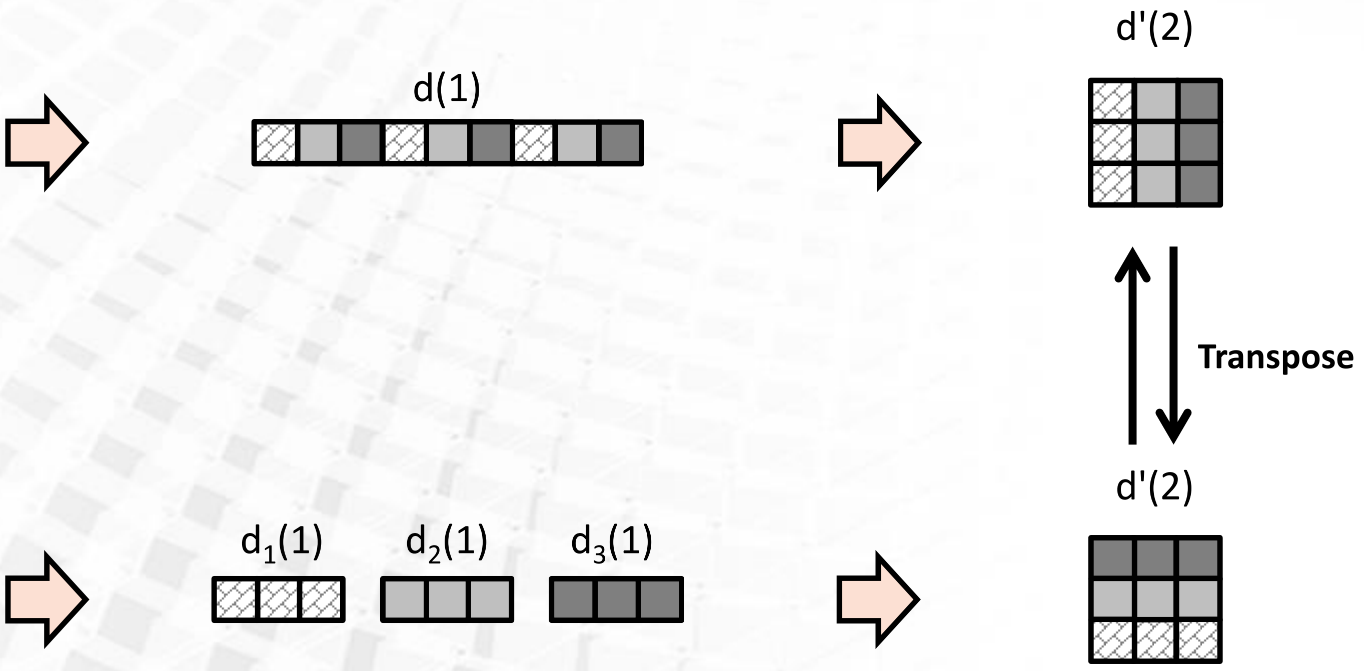
DATA LAYOUT TRANSFORMATION 2: AOS-TO-SOA TRANSFORMATION

AoS

```
record aos {
  var x: real;
  var y: real;
  var z: real;
}

var D: domain(1) = 1..3;
var A: [D] aos;
```

SoA

```
var N = 1..3;
record soa {
  var x : [N] real;
  var y : [N] real;
  var z : [N] real;
}

var A  = new soa();
```



Declaration | **Domain Representation** | **Transformed 2D domain**

- Represent AoS as a rectangular domain
- Transpose domain to get from AoS to SoA

EXAMPLE AOS TO SOA IN CHAPEL

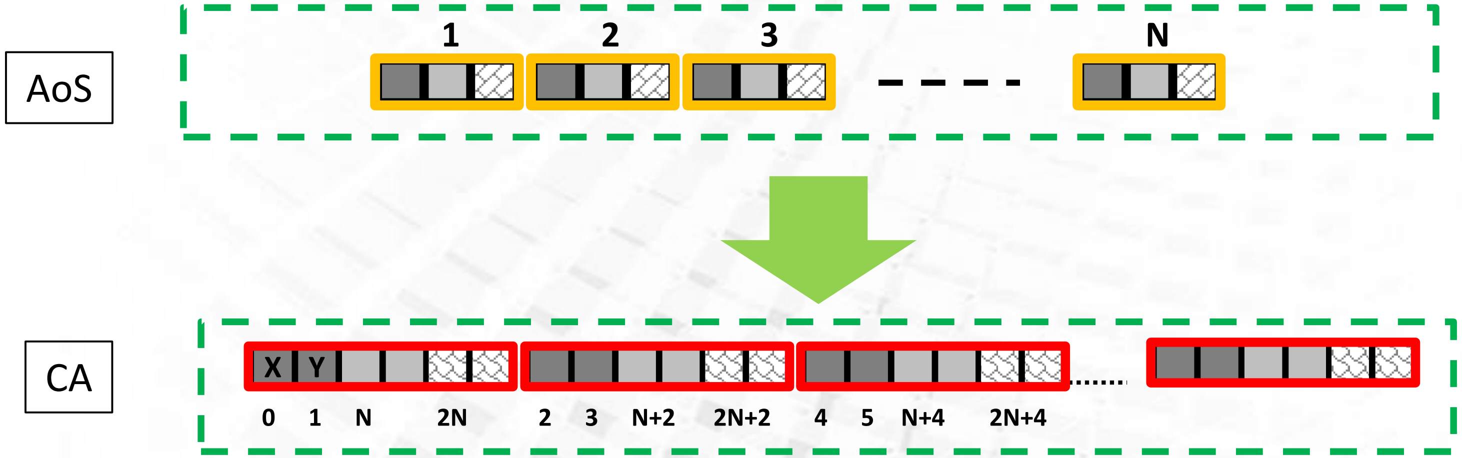
```
var D: domain(1) = 1 .. N;
record pixel {
  var r: real;
  var g: real;
  var b: real;
}

var src : [D] pixel;
var dst : [D] pixel;

on Locales[0].GPU do {
  forall i in 1..N {
    dst[i].r = src[i].r * v0 – src[i].g * v1;
    ...
}
```

Before

```
use LayoutTransposed;   // layout transform module

record pixel {
  var r: real; var g: real; var b: real;
}

var DomSoA : domain(2) dmapped Transposed() = {1..3, 1..N};

var src : [DomSoA] real;   // array of element type
var dst : [DomSoA] real;   // array of element type

on Locales[0].GPU do {
   forall i in 1..N
     dst[1,i] = src[1,i] * v0 - src[2,i] * v1;
     ...
}
```

After

DATA LAYOUT TRANSFORMATION 3: COMPRESSED ARRAY LAYOUT



- Fields within an AoS are coalesced to reduced memory divergence and improve register usage
- Tiling for improved cache locality and local memory usage
- Repositioning to handle sparse access of data
- All three done within the same Compressed Array (CA) domain map

EXAMPLE CA TRANSFORMATION IN CHAPEL

```
var D: domain(1) = 1 .. N;
record pixel {
  var r: real;
  var g: real;
  var b: real;
}

var src : [D] pixel;
var dst : [D] pixel;

on (Locales[0]:LocaleModel).GPU do {
  forall i in 1 .. N {
    dst[i].r = src[i].r * v0 – src[i].g * v1;
    ...
}
```

Before

```
use LayoutCA;   // layout transform module

record pixel {
  var r: real; var g: real; var b: real;
}

param t = getTileSize();   // source code analysis
param s = getSparsity();   // source code analysis

var DomCA : domain(2) dmapped CA(t,s) = {1..3, 1..N};

var src : [DomCA] real;   // array of element type
var dst : [DomCA] real;   // array of element type

on (Locales[0]:LocaleModel).GPU do {
   forall i in 1..N
     dst[1,i] = src[1,i] * v0 - src[2,i] * v1;
     ...
}
```

After

IMPLICATIONS OF DATA LAYOUT ON MEMORY DIVERGENCE

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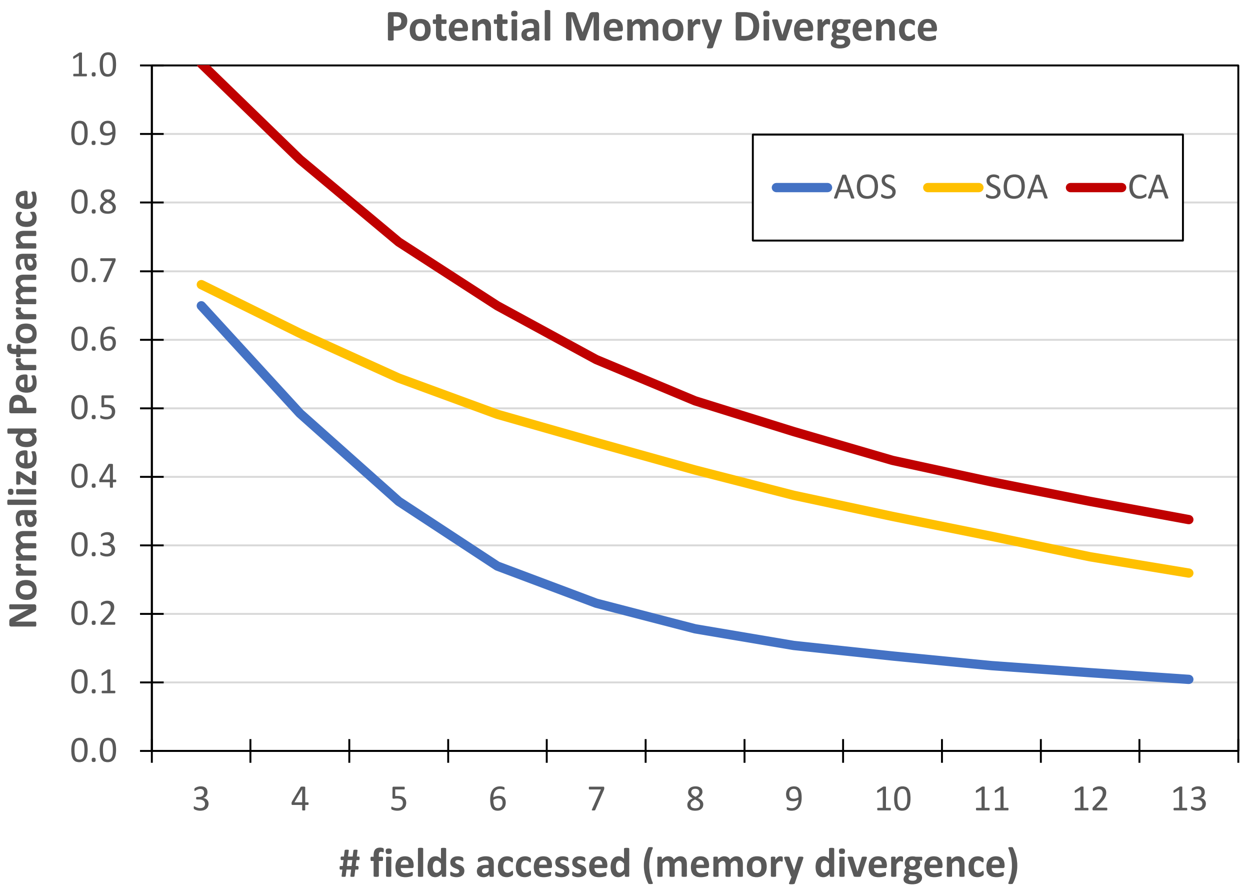
- Platform:
  - AMD A10-8700B APU
- Running synthetic micro-kernels tunable for
  - Arithmetic intensity
  - Problems size
  - Data access patterns
- Potential Memory Divergence (PMD) = estimate of expected memory divergence based on access patterns
- Performance normalized to CA at PMD of 3 (higher is better)



CONCLUSIONS AND FUTURE WORK

- We demonstrate that the domain map feature of Chapel can be useful in implementing sophisticated data layout transformations
  - Column Major
  - AoS to SoA
  - Compressed Array

- Future work
  - Explore fully automatic approaches for data layout transformation
  - Explore collaborative design patterns
  - Extend work to discrete GPU nodes

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DISCLAIMER & ATTRIBUTION

ATTRIBUTION