Metacca – Metaprogramming for Accelerators

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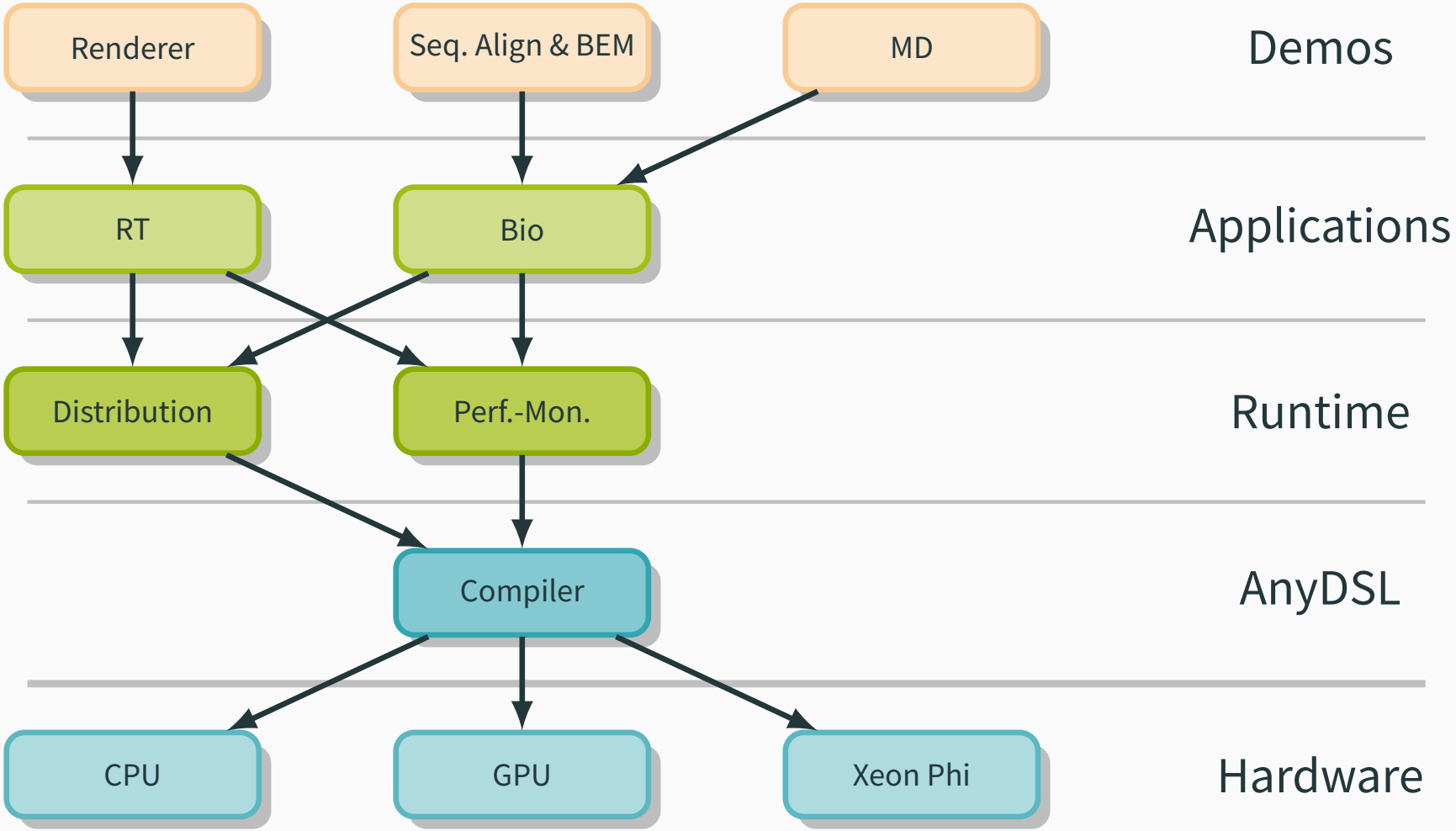
UNIVERSITÄT DES SAARLANDES

SIC Saarland Informatics Campus

Project Overview



Partial Evaluation

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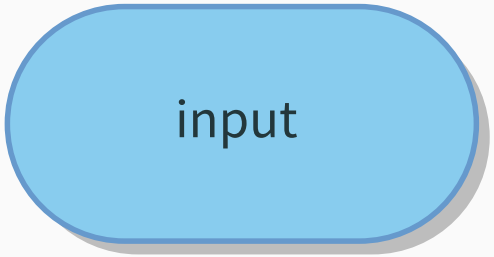

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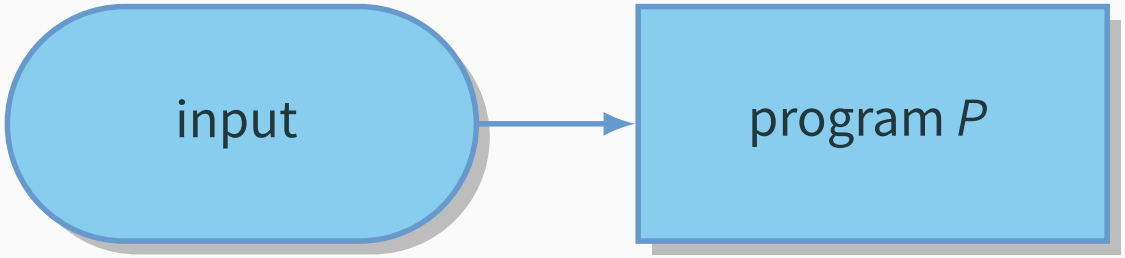

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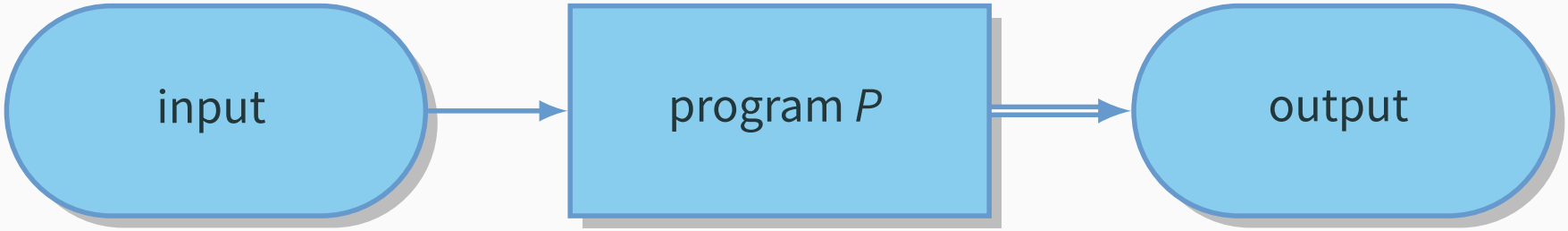

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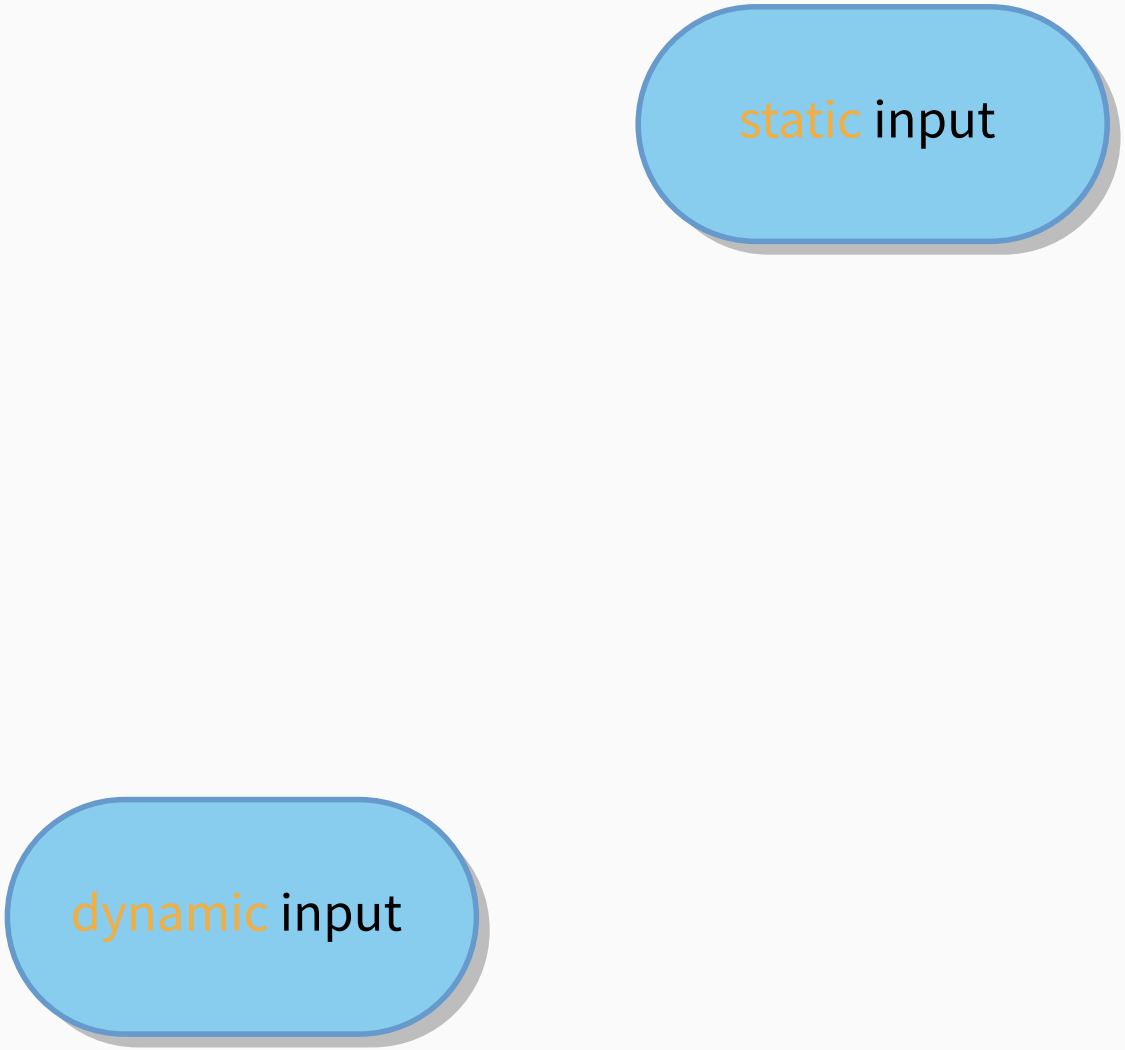

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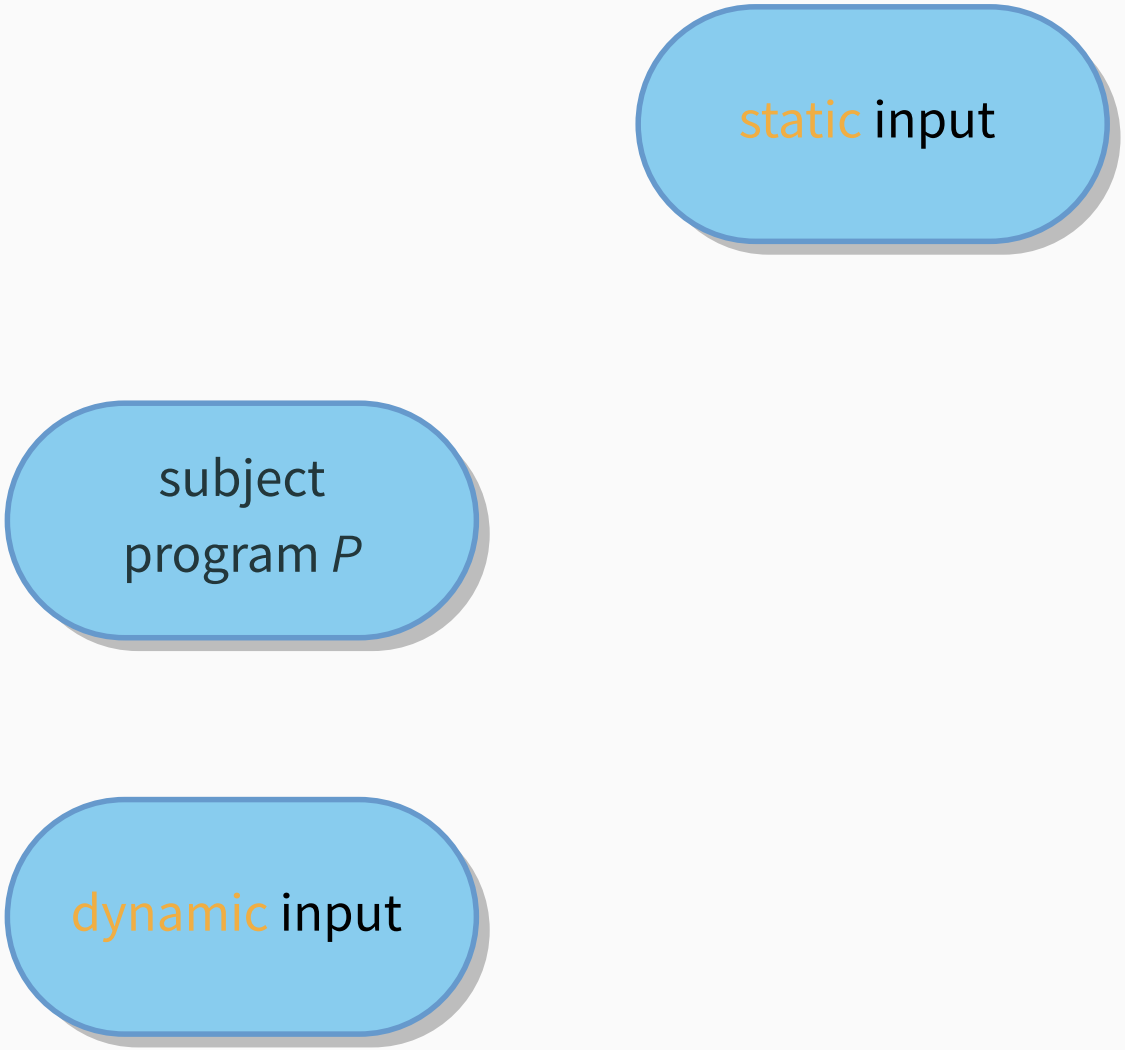

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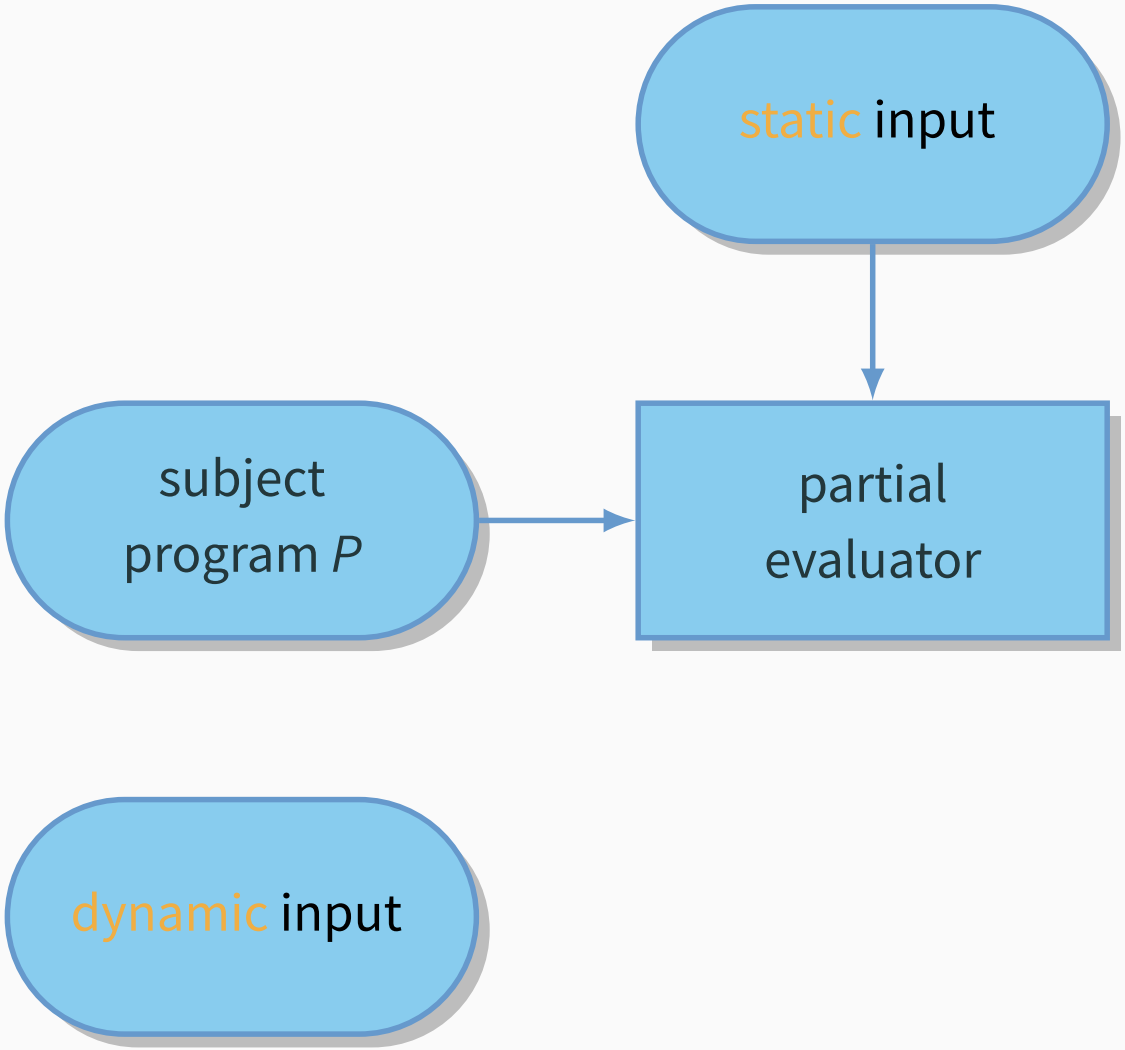

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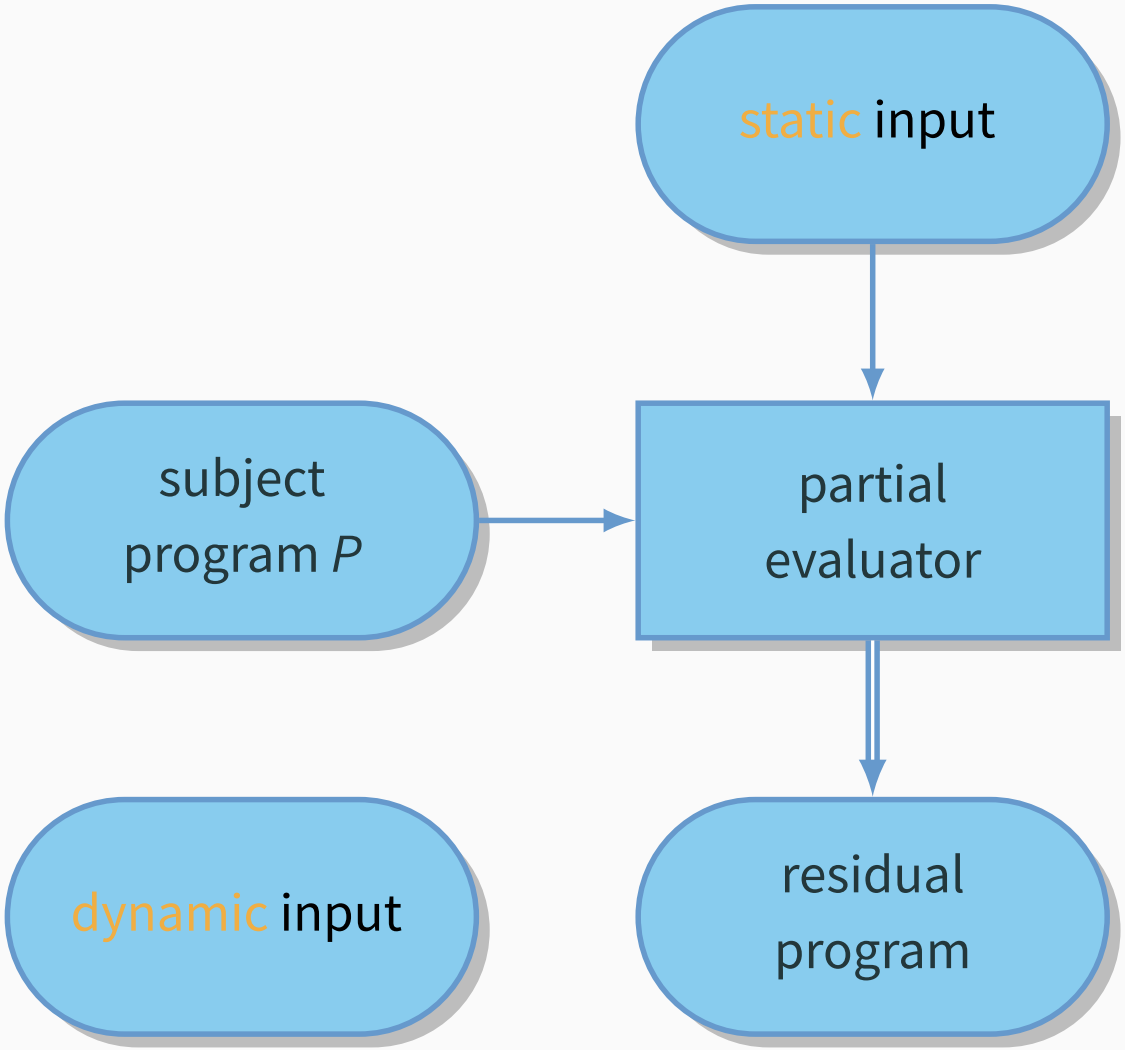

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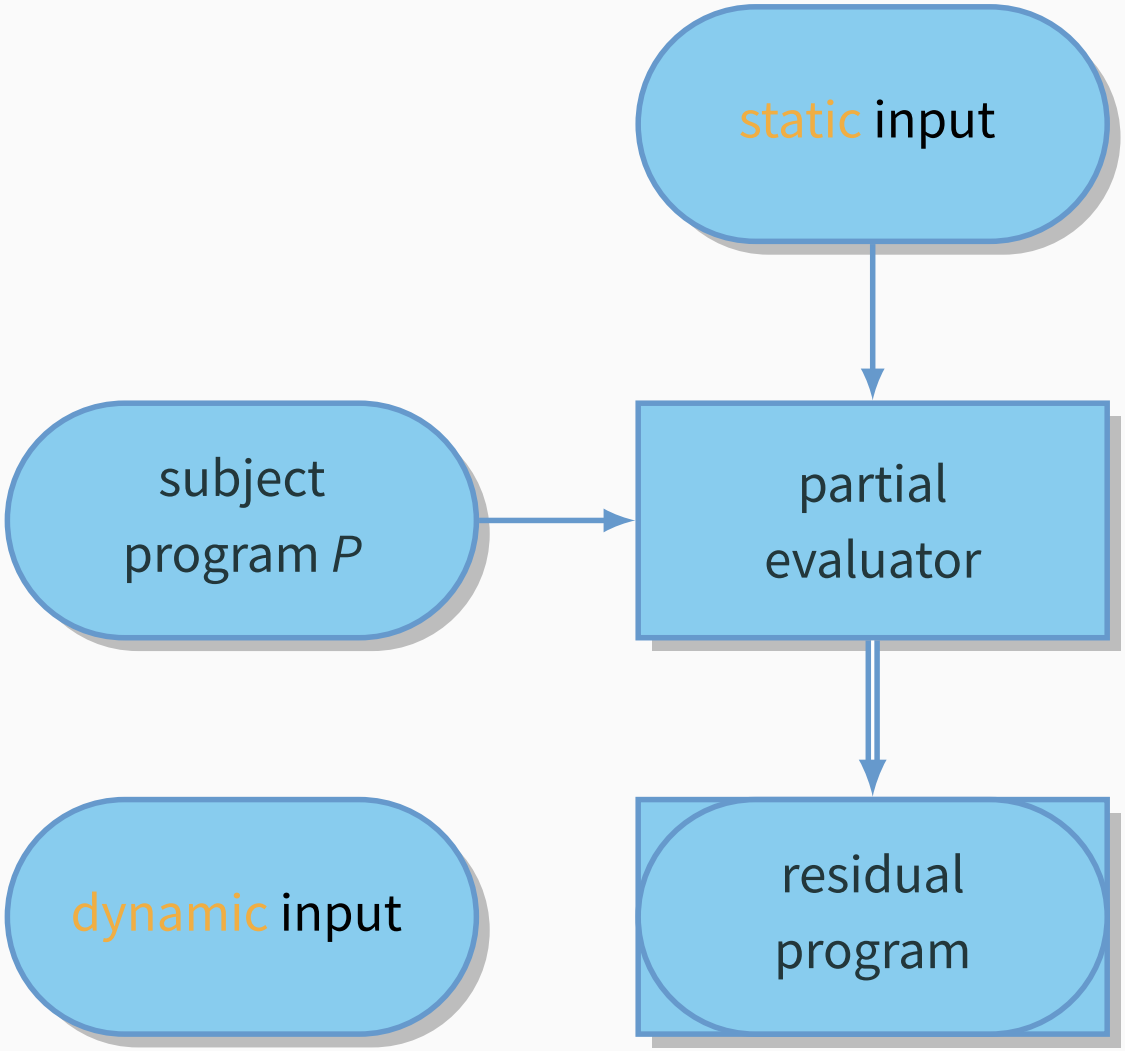

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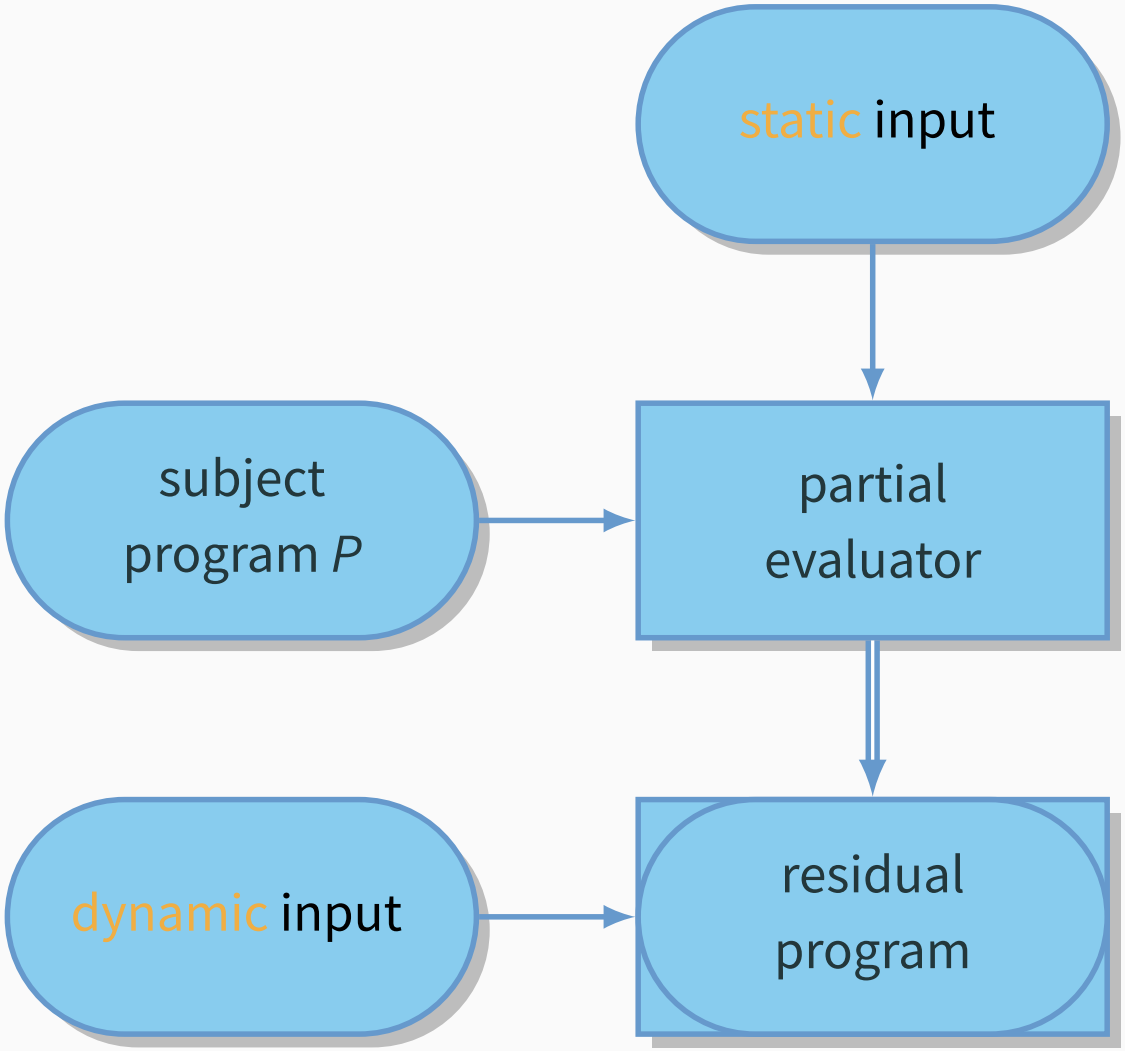

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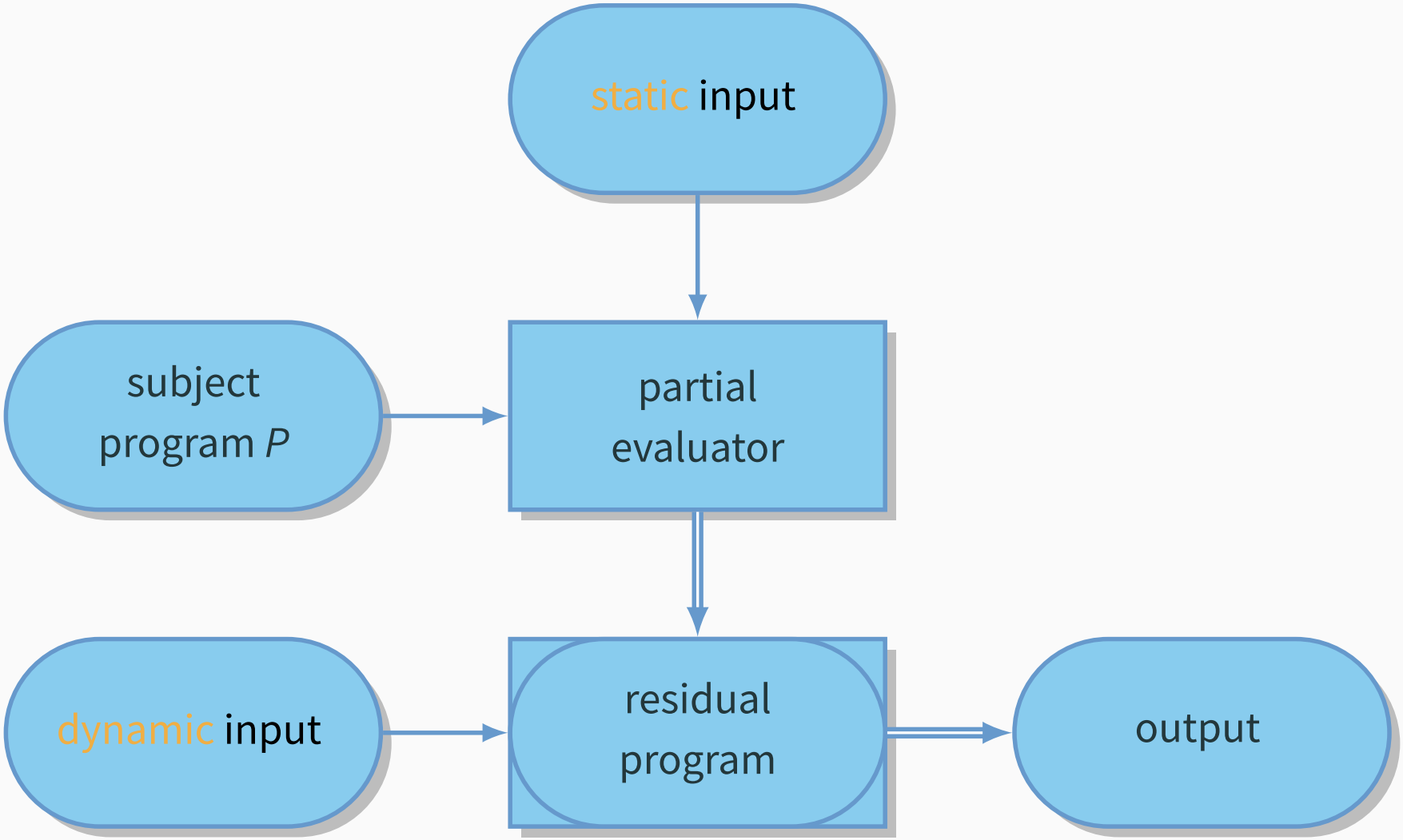

Typical Use-Cases

- Higher-order Parameters:

  $\Rightarrow$ auto-annotated

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Advantages over manual metaprogramming

- Polyvariance
- No clumsy quotations
- Well-typedness of the residuum

Target-specific Code Generation

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```
parallel(num_threads, a, b, |i| {
    body
});
```

Target-specific Code Generation

```
for i in parallel(num_threads, a, b) {
    body
}
```

Target-specific Code Generation

```
for i in vectorize(simd_width, a, b) {
    body
}
```

Target-specific Code Generation

```
for x, y in cuda(grid, block, a, b) {
    body
}
```

Target-specific Code Generation

```
for x, y in opencl(grid, block, a, b) {
    body
}
```

Target-specific Code Generation

```
for y in parallel(4, y_begin, y_end) {
    for x in vectorize(8, x_begin, x_end) {
        body
    }
}
```

Program Transformations: Combining Loops

```
type Loop1D = fn(int,      int,      fn(int)      -> ()) -> ();
type Loop2D = fn(int, int, int, int, fn(int, int) -> ()) -> ();

fn combine(loop_x: Loop1D, loop_y: Loop1D) -> Loop2D {
    |x_begin, y_begin, x_end, y_end, body|
        loop_y(y_begin, y_end, |y|
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```
for x, y in combine(range, range)(bounds) {
    body
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```

```
let vec = @|num||a, b, body| vectorize(num, a, b, body);
let par = @|num||a, b, body|  parallel(num, a, b, body);

for x, y in combine(vec(8), par(4))(bounds) {
    body
}
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}
```

```
let bounds = (x_begin, y_begin, x_end, y_end);
```

```
let vec = @|num||a, b, body| vectorize(num, a, b, body);
let par = @|num||a, b, body|  parallel(num, a, b, body);

for x, y in tile(512, 32, vec(8), par(4))(bounds) {
    body
}
```

Image Processing: User Code

```
let blur_x = |x, y|
  (img.get(x-1, y) + img.get(x, y) + img.get(x+1, y)) / 3;
let blur_y = |x, y|
  ( blur_x(x, y-1) +  blur_x(x, y) +  blur_x(x, y+1)) / 3;

let seq = combine_xy(range, range);
let opt = tile(512, 32, vec(8), par(16));
let gpu = tile_cuda(32, 4);

compute(out_img_seq, seq, blur_y);
compute(out_img_opt, opt, blur_y);
compute(out_img_gpu, gpu, blur_y);
```

Image Processing: Implementation

```
type BinOp = fn(i32, i32) -> i32;

fn compute(out: Img, loop: Loop2D, op: BinOp) -> BinOp {
  for x, y in loop(0, 0, img.width, img.height) {
    out.set(x, y, op(x, y))
  }
  |x, y| out.get(x, y)
}
```

Performance

Blur: Ours vs. Halide

CPU: +12%

GPU: +7%

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CPU: +12%

GPU: +7%

Harris-Corner: Ours vs. Halide

CPU: +37%

GPU: +44%

Other Demos

Ray Traversal

Embree: -15% to +13%

Optix: -19% to -2%

ARM support

Other Demos

Ray Traversal

Embree: -15% to +13%

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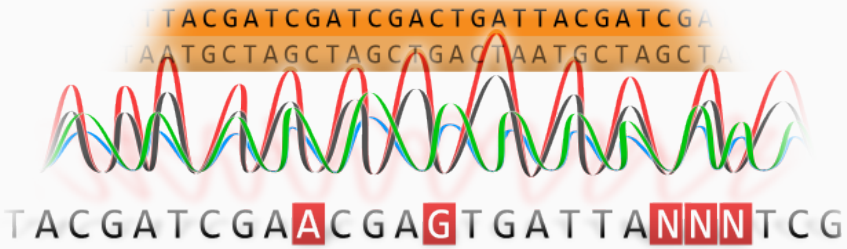
ARM support

Genome Sequence Alignment

SeqAn/Parasail: -3% to +11%

NVBIO: -3% to +10%



Renderer

AnyDSL Renderer

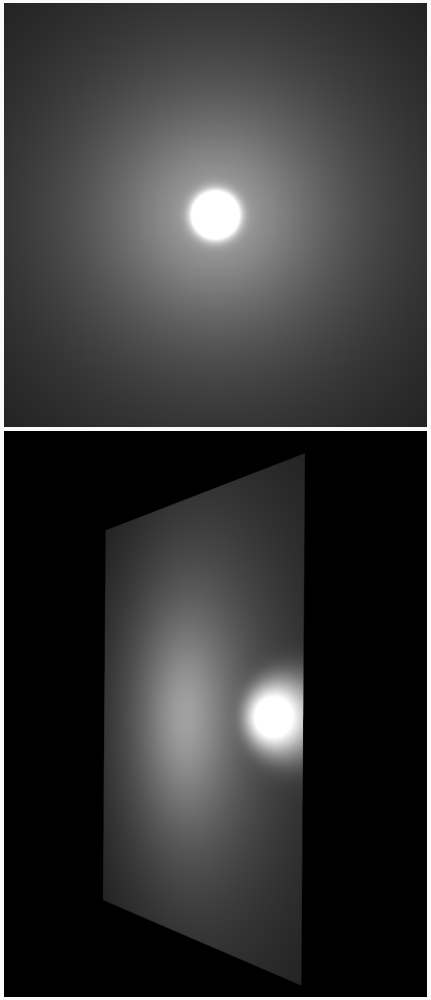
- Now a complete renderer (PT)
- Lights & Materials controlled by shaders
- CPU: Vectorized
- 2 GPU versions: Megakernel, Streaming

Diffuse Shader

```
fn @shader(math: Intrinsics,
           scene: Scene,
           ray: Ray,
           hit: Hit,
           surf: SurfaceElement
           ) -> Material {
  let kd = make_color(0.6f, 0.6f, 0.6f);
  let bsdf = make_diffuse_bsdf(surf, kd);
  make_material(bsdf)
}
```

Glossy Shader

```
fn @shader(math: Intrinsics,
           scene: Scene,
           ray: Ray,
           hit: Hit,
           surf: SurfaceElement
           ) -> Material {
  let kd = make_color(0.6f, 0.6f, 0.6f);
  let diff = make_diffuse_bsdf(surf, kd);
  let ks = make_color(0.5f, 0.5f, 0.5f);
  let ns = 96.0f;
  let spec = make_phong_bsdf(surf, ks, ns);
  let k = 0.6f / (0.5f + 0.6f);
  let bsdf = make_mix_bsdf(diff, spec, k);
  make_material(bsdf)
}
```



Textures

```
fn @shader(math: Intrinsics,
           scene: Scene,
           ray: Ray,
           hit: Hit,
           surf: SurfaceElement
           ) -> Material {
  let texture = make_texture(
      math,
      make_repeat_border(),
      make_bilinear_filter(),
      scene.images(0)
  );
  let uv = vec4_to_2(surf.attr(0));
  let kd = texture(uv);
  let bsdf = make_diffuse_bsdf(surf, kd);
  make_material(bsdf)
}
```

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fn @shader(math: Intrinsics,
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           surf: SurfaceElement
           ) -> Material {
  let texture = make_texture(
      math,
      make_clamp_border(),
      make_bilinear_filter(),
      scene.images(0)
  );
  let uv = vec4_to_2(surf.attr(0));
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           surf: SurfaceElement
           ) -> Material {
  let texture = make_texture(
      math,
      make_repeat_border(),
      make_bilinear_filter(),
      scene.images(0)
  );
  let uv = vec4_to_2(surf.attr(0));
  let kd = texture(uv);
  let bsdf = make_diffuse_bsdf(surf, kd);
  make_material(bsdf)
}
```

Performance

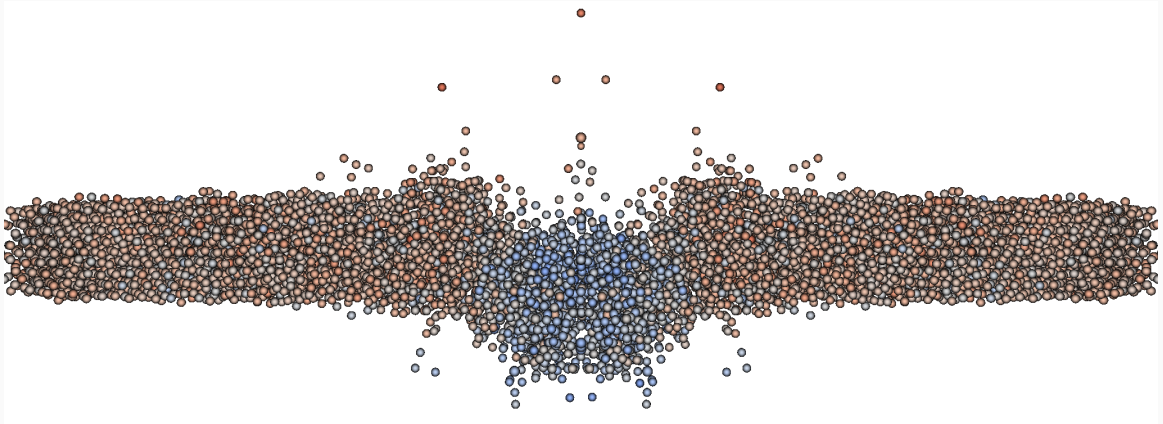
Preliminary results: 31 FPS on GPU, 9 FPS on CPU

AnyDSL FPGA Support

- Funded via IVCI
- In collaboration with Akif Ötzkan (FAU Erlangen-Nuremberg)
- C-based backends for Altera OpenCL and Vivado HLS
- Prototype mapping for stencil codes
- Good performance compared to Halide & Hipacc

Molecular Dynamics

Code Generation for Molecular dynamics



- Simulation of the trajectories of a large number of particles based on their interactions
- The computation of short-range interactions is an important use case in many simulations
- Most implementations employ a combination of **cell decomposition** and **neighbor lists**

Kernel Generation through Partial Evaluation

```
// example application
// the kernel is passed as an anonymous function here
execute(particles, |pi, ci, cluster_size| {
    // update particle pi in cluster ci
});
```

- By partially evaluating **execute** with respect to its second argument, code generation is triggered.
- All details about the target platform are hidden within its implementation
- To generate code for different platforms, different implementations must be provided

Kernel Generation on the CPU

```
fn execute(particles: Particles, kernel: Kernel) -> () {
    for ci in parallel(/*...*/) {
        // ...
        for i in vectorize(/*...*/) {
            kernel(/*...*/);
        }
    }
}
```

Kernel Generation on the GPU

```
fn execute(particles: Particles, kernel: Kernel) -> () {
    let acc = get_accelerator(device_id);
    let size = particles.number_of_clusters;
    let grid = (size * get_cluster_size(), 1, 1);
    let block = (get_cluster_size(), 1, 1);
    for bid, bdim, gid in acc.exec(grid, block) {
        let (gidx, _, _) = gid;
        let (bidx, _, _) = bid;
        let (bdimx, _, _) = bdim;
        kernel(gidx(), bidx(), bdimx());
    }
    acc.sync();
}
```

Single-Core Performance in FLOPS/cycle

Benchmark settings

- AnyDSL: LLVM version 5.0.1 with RV for vectorization, -O3, -march=native
- MiniMD: Intel C compiler version 18 with -O3, -xHost, -qopt-zmm-usage=high (SKL)
- Double-precision floating-point computations

Processor	AnyDSL	MiniMD
Skylake	5.816 (AVX512)	3.618 (AVX512)
Broadwell	2.928 (AVX2)	1.695 (AVX2)
Ivy Bridge	2.103 (AVX)	1.034 (AVX)

Acceleration on the GPU

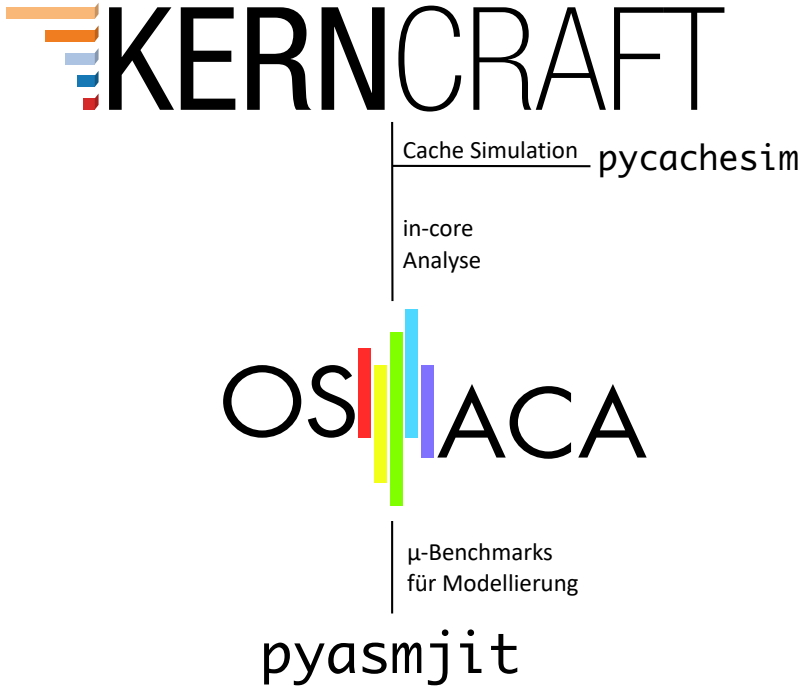
- CPU test platform: Intel Xeon E3-1275 v5 with four cores
- GPU test platform: NVIDIA GTX 1080, AnyDSL Backend: NVVM, Cluster size: 32
- Double-precision floating-point computations
- The generated GPU code runs around 5 times faster

Particles	AnyDSL (AVX2)	AnyDSL (GPU)
100 000	1044.39 ms	194.101 ms
500 000	4300.2 ms	826.627 ms
1 000 000	7652.97 ms	1684.18 ms
2 000 000	15014.7 ms	3294.85 ms

Performance Monitoring

RRZE: Aktuelle Arbeiten

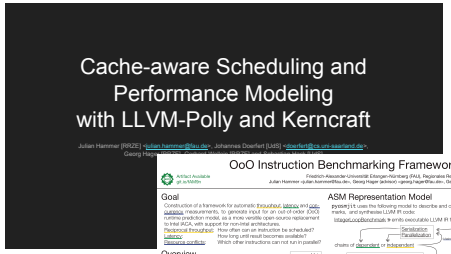
- `Kerncraft` & `pycachesim`: Laufzeitvorhersage für Kernels
- `OSACA`: In-core Laufzeitvorhersage für Assembler Basic Blocks
- `pyasmjit`: Micro-Benchmark Generierung für Modellierung
- Automatische Modellbildung, gemeinsam mit Univ. Saarlandes



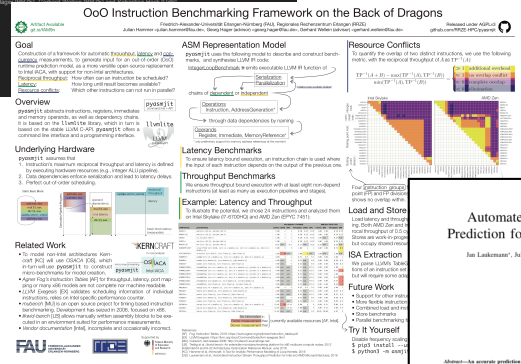
Julian Hammer <julian.hammer@fau.de>

RRZE: Aktuelle Beiträge

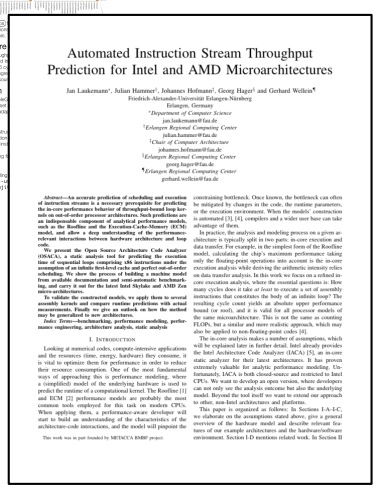
- Workshopbeitrag auf LLVM-CGO18 über automatisches Blocking in LLVM, gemeinsam mit Universität des Saarlandes



- Poster bei SC18 über pyasmjit



- Workshoppaper bei PMBS18 (in review) über OSACA



Conclusions

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- Partial evaluation for zero-cost abstractions
- Target-specific code generation triggered via higher-order functions
- $\Rightarrow$ High-performance libraries that hide hardware peculiarities

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- Partial evaluation for zero-cost abstractions
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Thank you. Questions?