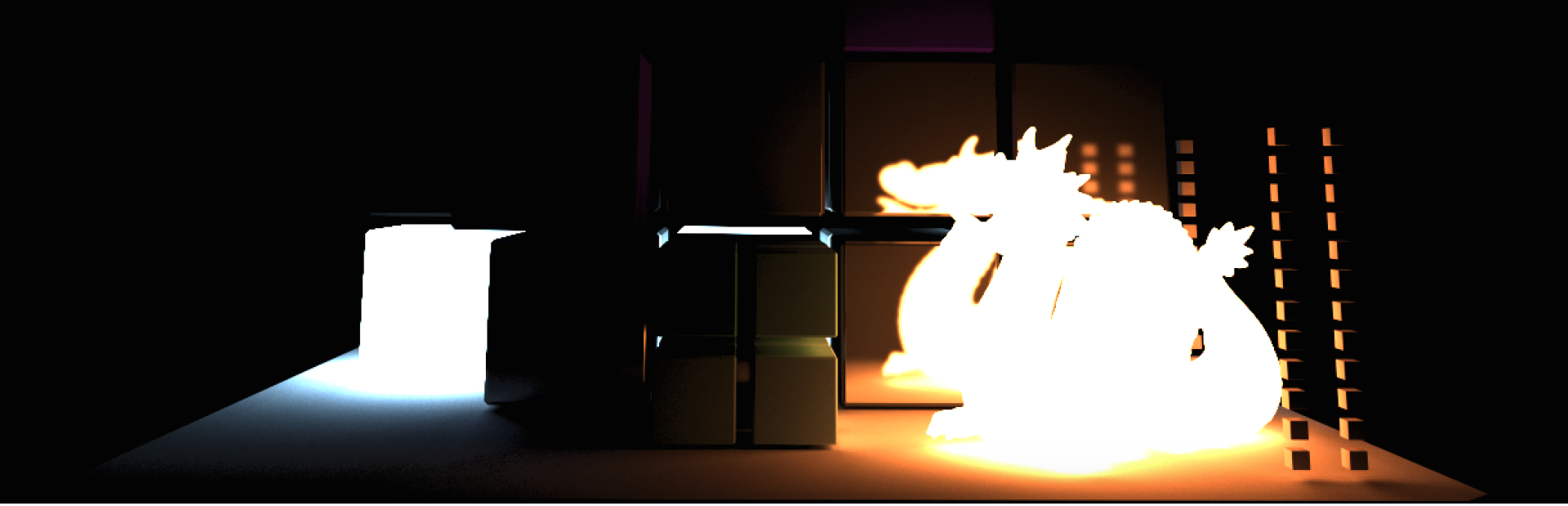
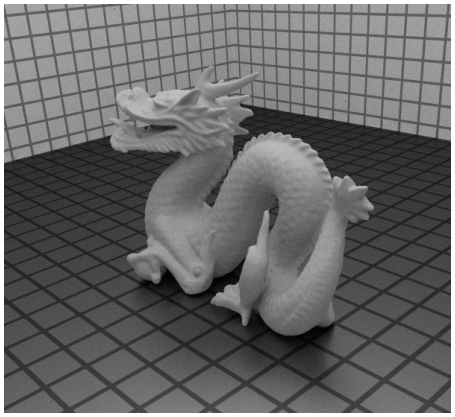


VISIONARAY

A Modern C++ Framework For Prototyping Ray Tracing Kernels



Stefan Zellmann
University of Cologne
zellmann(at)uni-koeln.de

Motivation

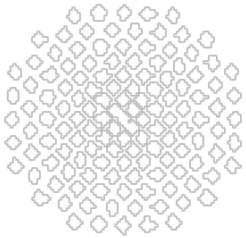
Visualization as a Service

- University of Cologne, Chair of Computer Science with emphasis on Scientific Visualization
- Several Virtual Reality installations (Powerwall, VR-Bench, CAVE, several HMDs)
- Visualization as a service for other institutes:
  - Natural sciences
  - Engineering
  - Geo sciences

Motivation

Scientific Visualization

- Applications:
  - Archaeology
  - Medical imaging
  - Virtual reality
  - Physics
  - (…)



Motivation

Scientific Visualization

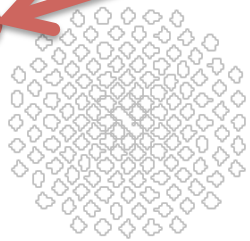
- Applications:
  - Archaeology
  - Medical imaging
  - Virtual reality
  - Physics
  - (…)

Photorealism

Motivation

Scientific Visualization

- Applications:
  - Archaeology
  - Medical imaging
  - Virtual reality
  - Physics
  - (…)

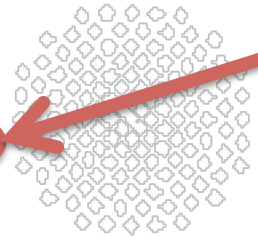


Quick insight, photorealism irrelevant

Motivation

Scientific Visualization

- Applications:
  - Archaeology
  - Medical imaging
  - Virtual reality
  - Physics
  - (…)



High realism in real-time

Motivation

Scientific Visualization

- Applications:
  - Archaeology
  - Medical imaging
  - Virtual reality
  - Physics
  - (…)

Higher-order interpolation
Implicit surfaces

Motivation

Scientific Visualization

- A “zoo” of 3D rendering algorithms
  - Direct volume rendering CT/MRI data
  - Path tracing for surfaces
  - Iso-surface rendering
  - Whitted-style ray tracing
  - …

Motivation

Scientific Visualization

- A "zoo" of 3D rendering algorithms
  - Direct volume rendering CT/MRI data
  - Path tracing for surfaces
  - Iso-surface rendering
  - Whitted-style ray tracing
  - …

Many are naturally implemented with ray tracing

Motivation

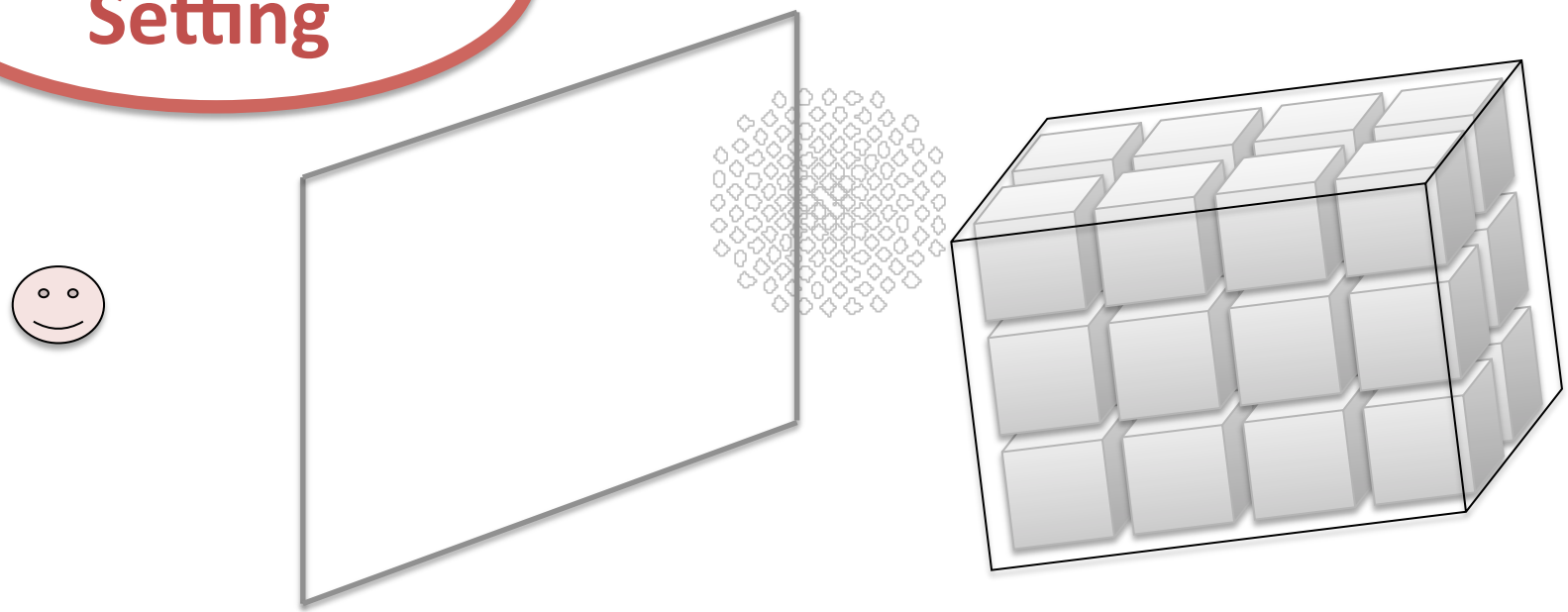
Direct Volume Rendering

Video not included in PDF slides

Motivation

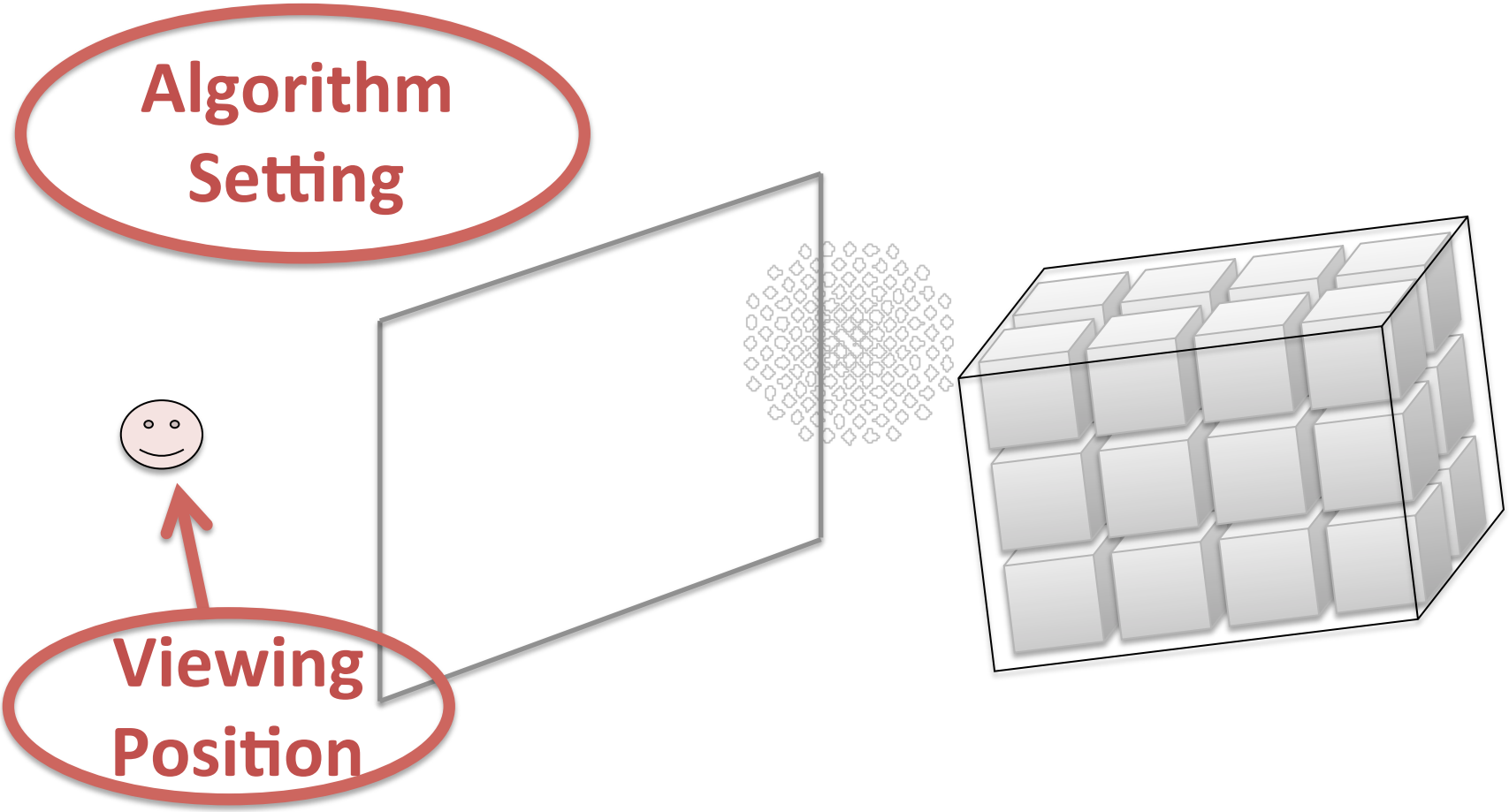
Direct Volume Rendering

Algorithm Setting



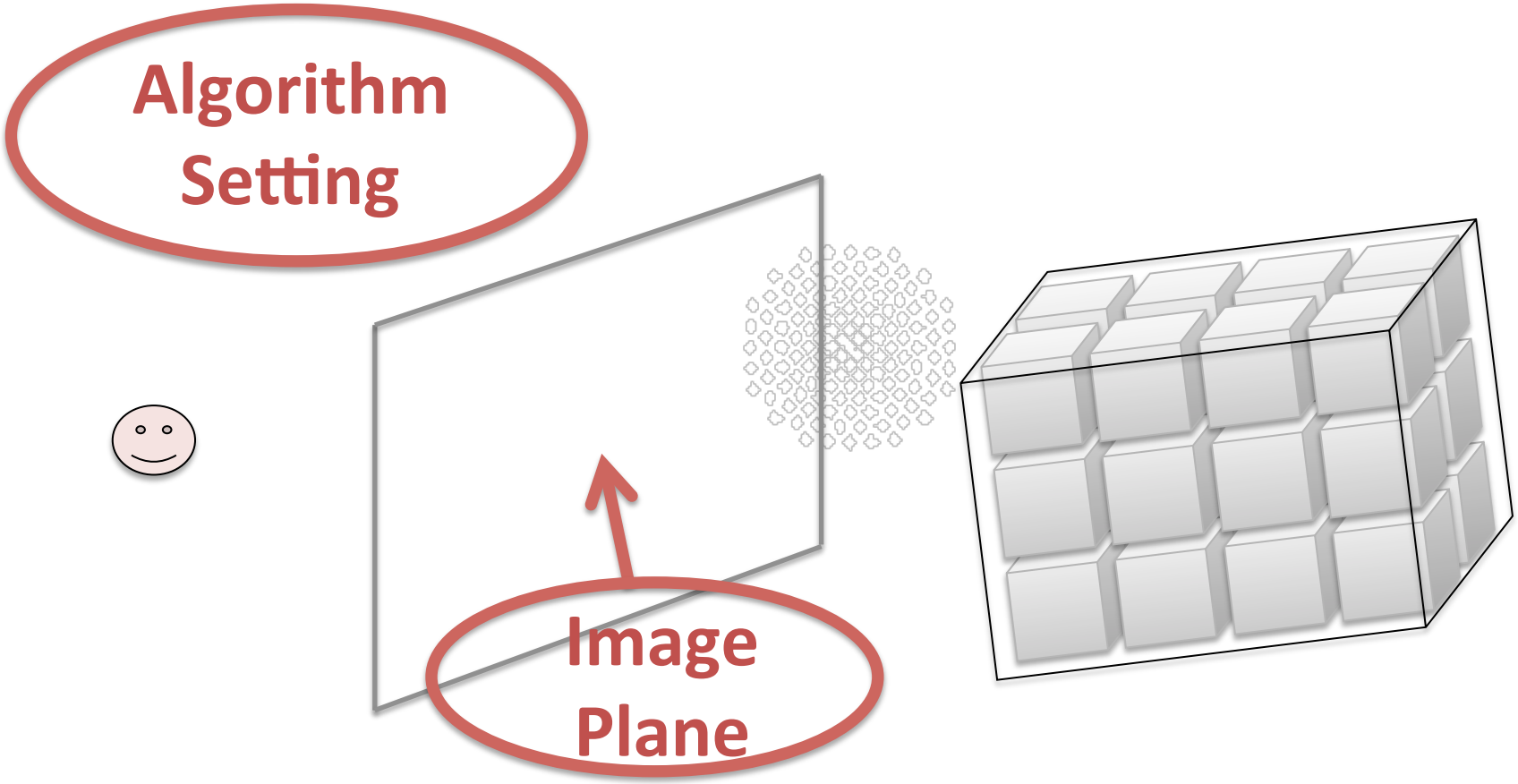
Motivation

Direct Volume Rendering



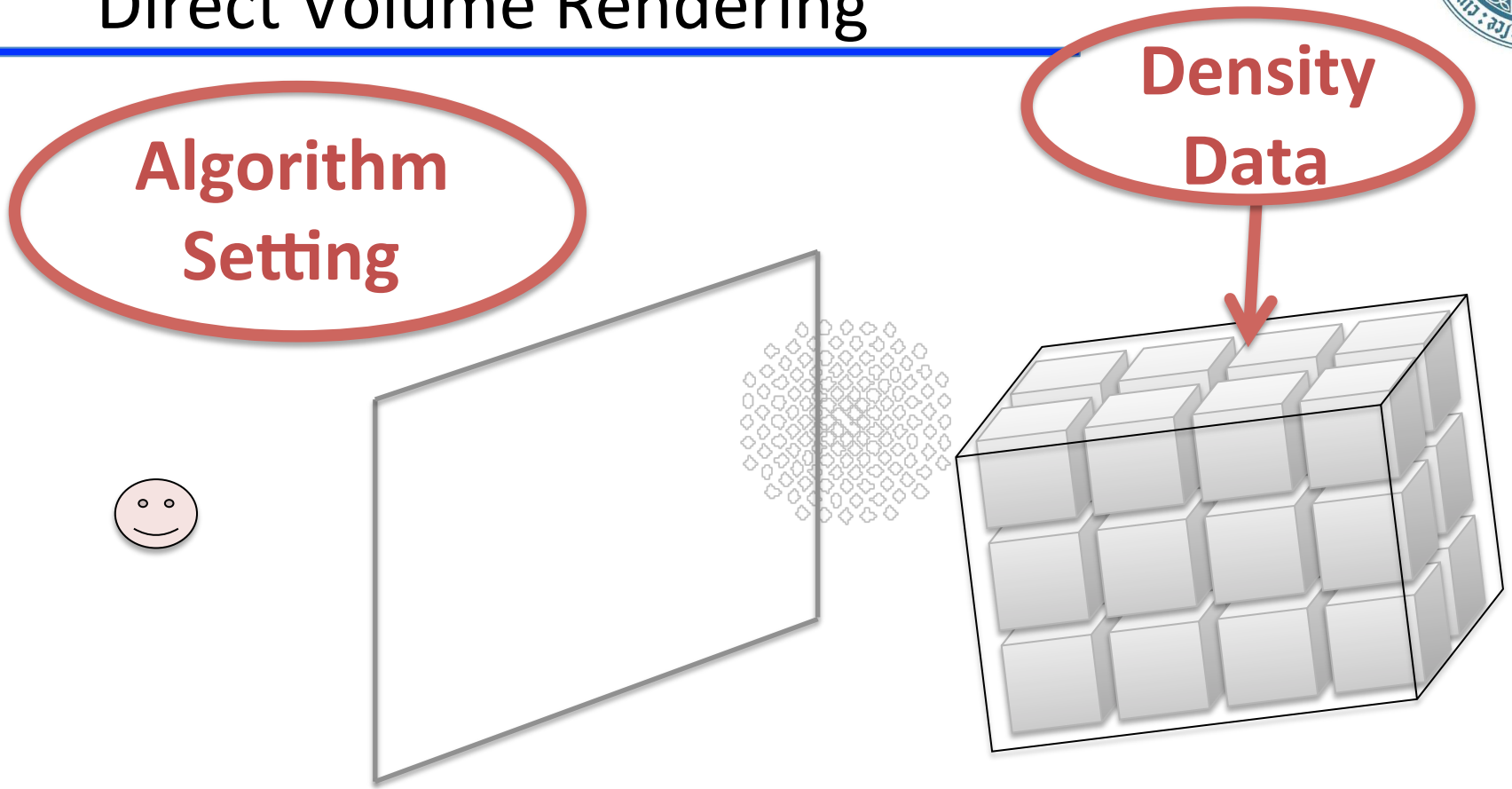
Motivation

Direct Volume Rendering



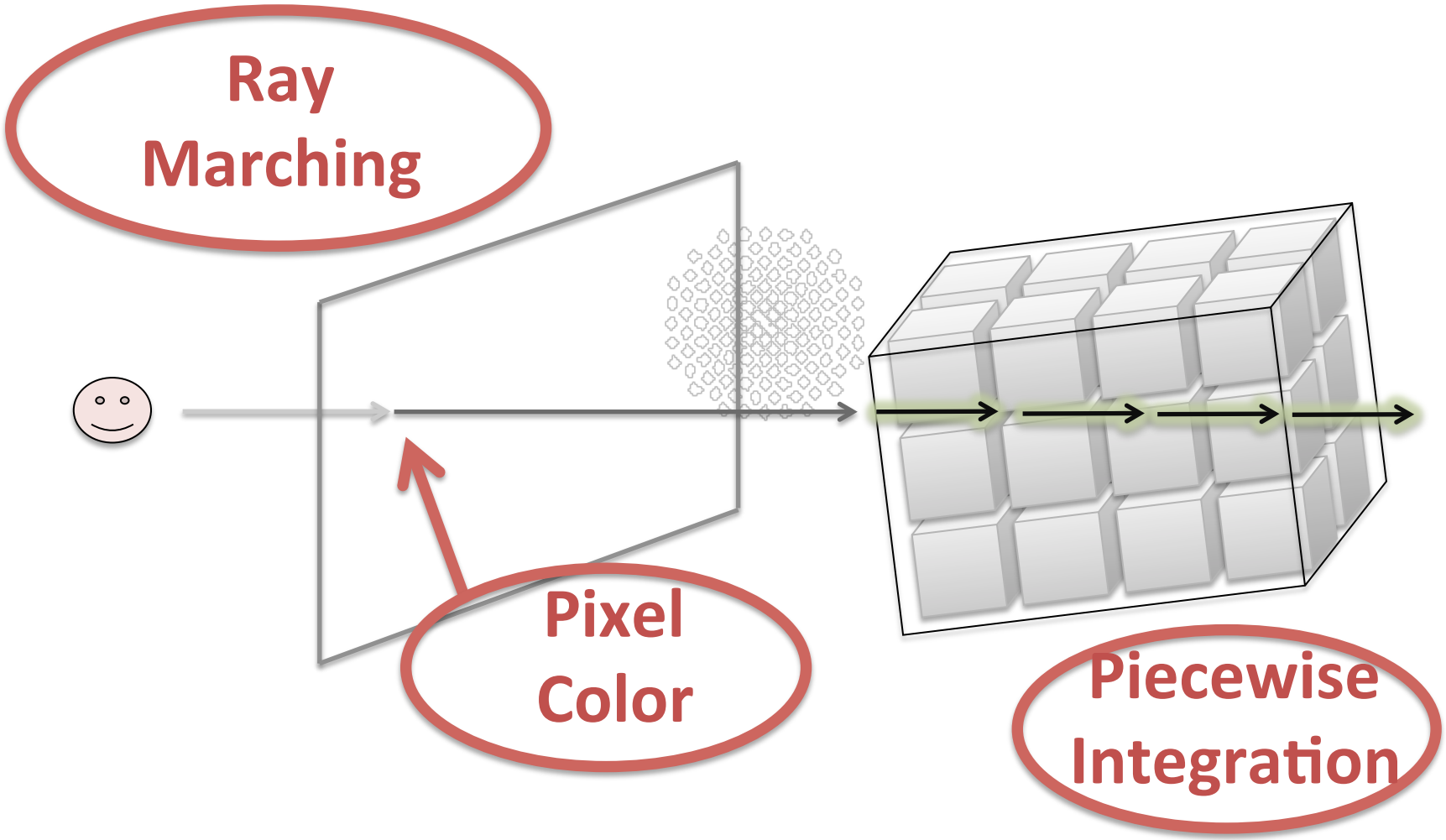
Motivation

Direct Volume Rendering



Motivation

Direct Volume Rendering



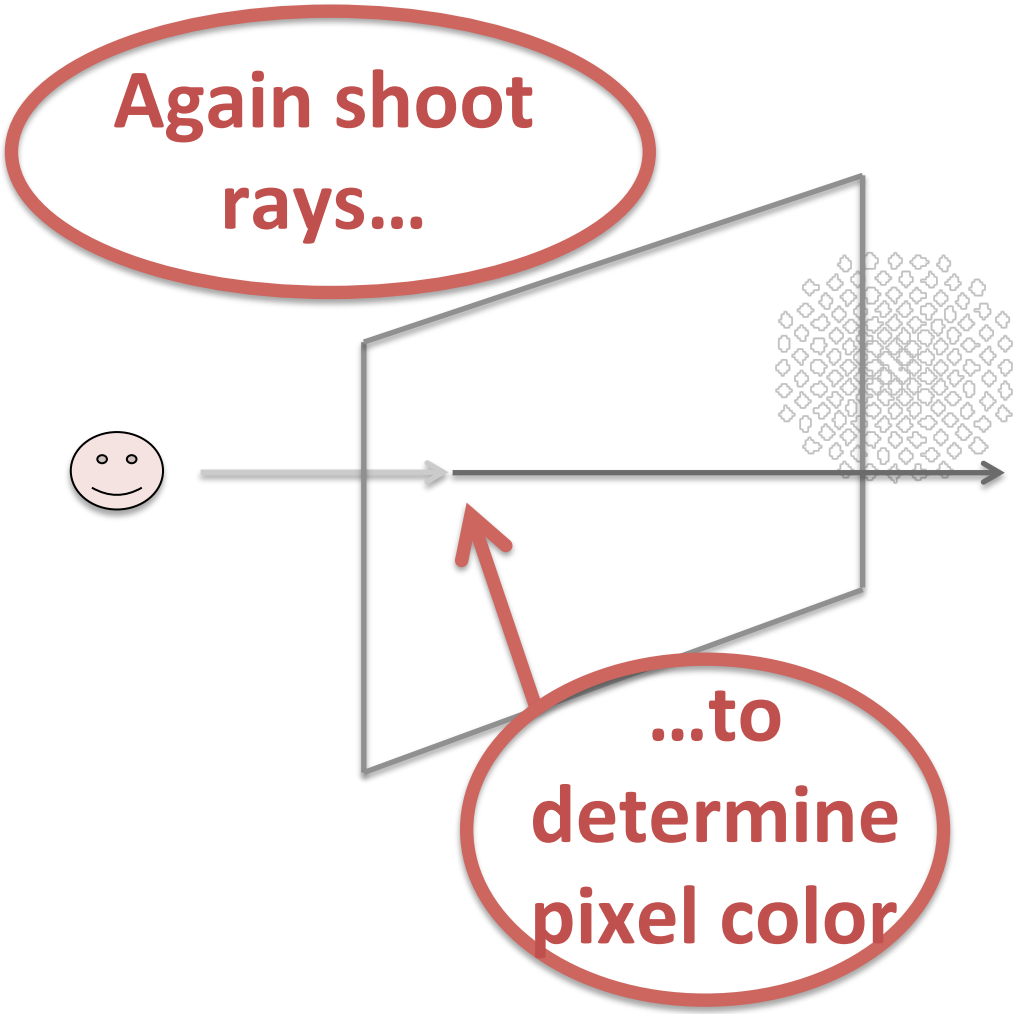
Motivation

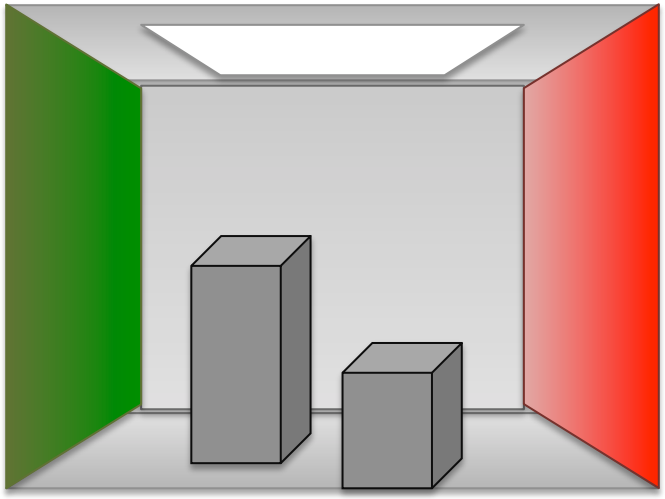
Path Tracing

Video not included in PDF slides

Motivation

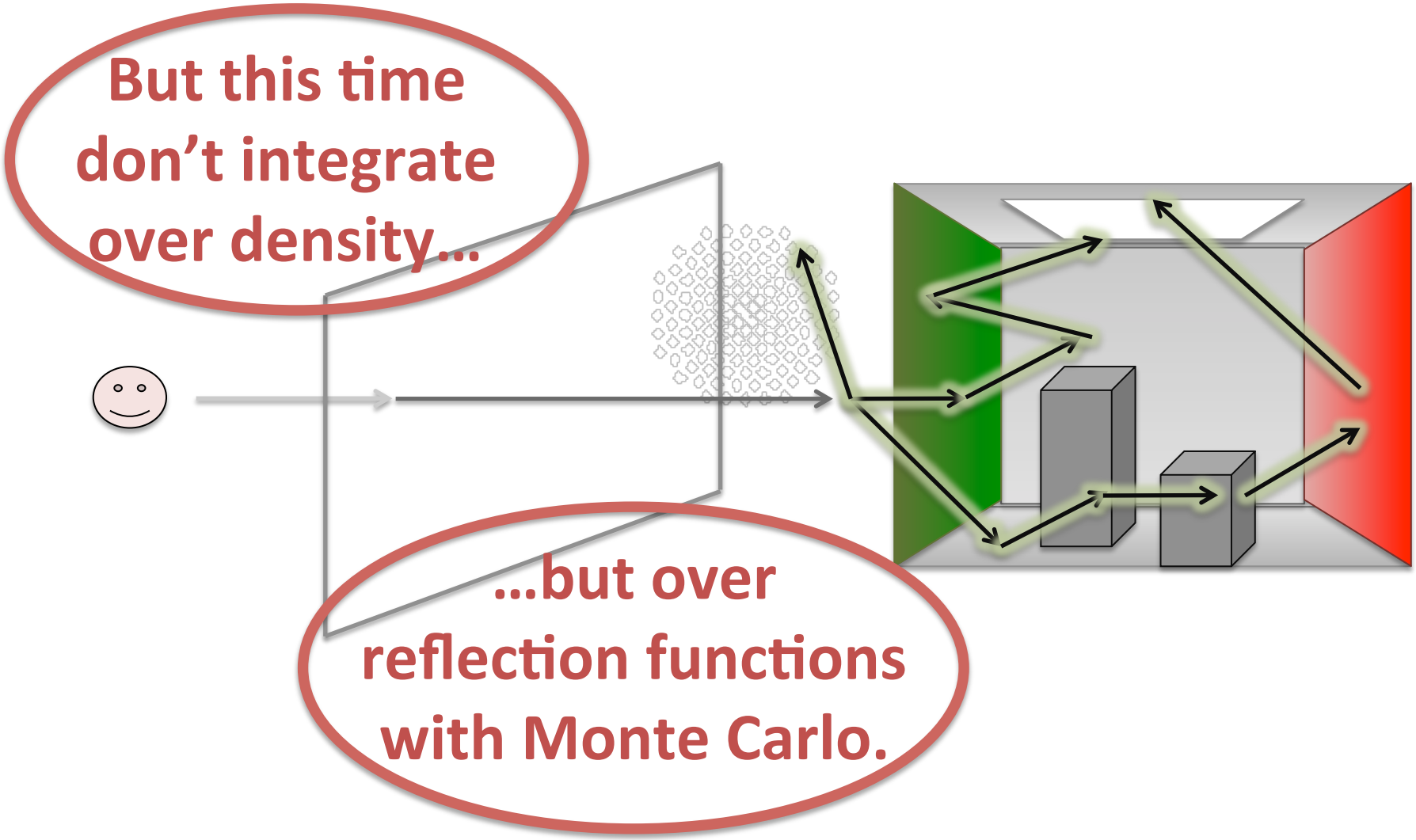
Path Tracing





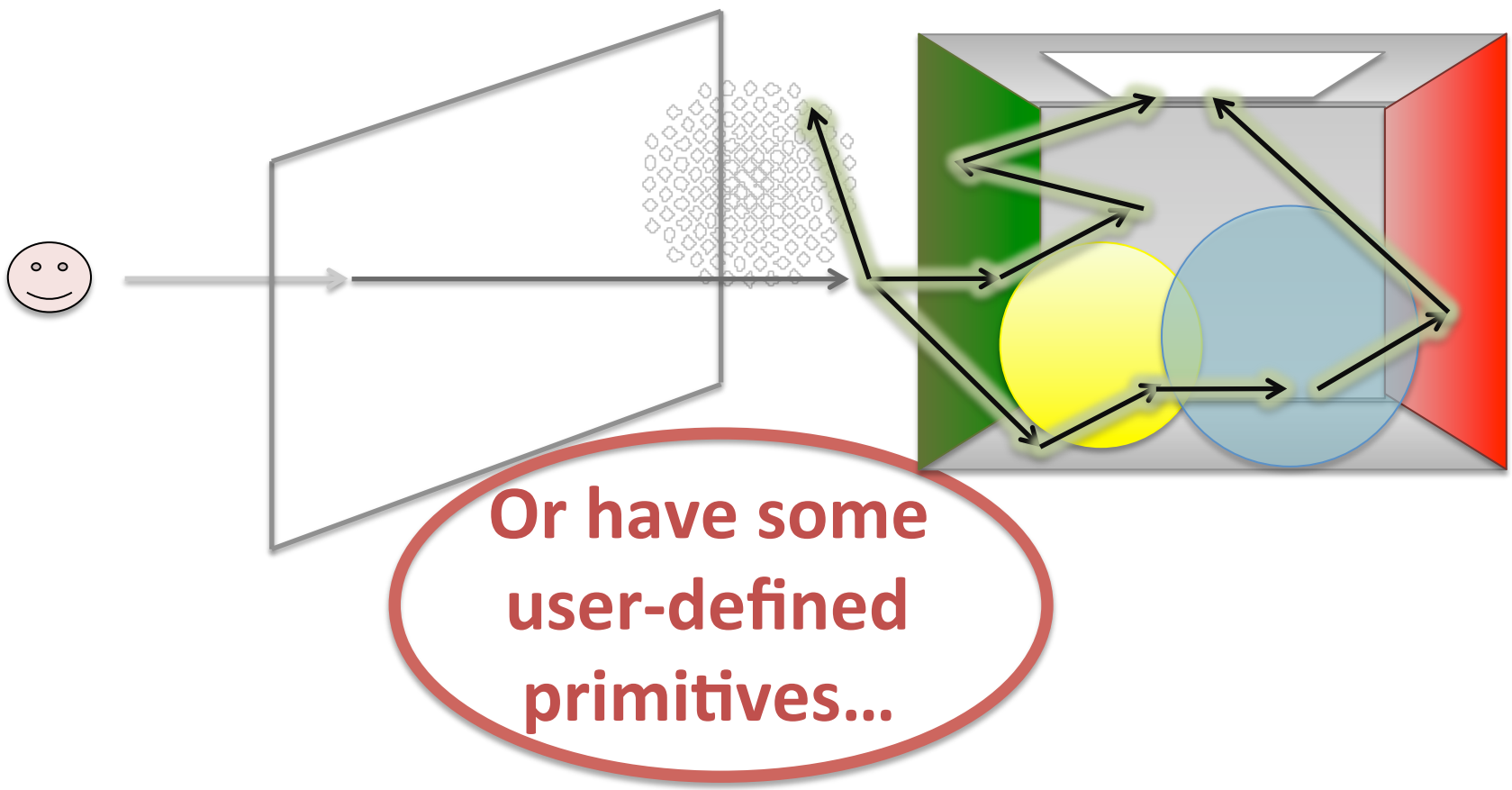
Motivation

Path Tracing



Motivation

Path Tracing



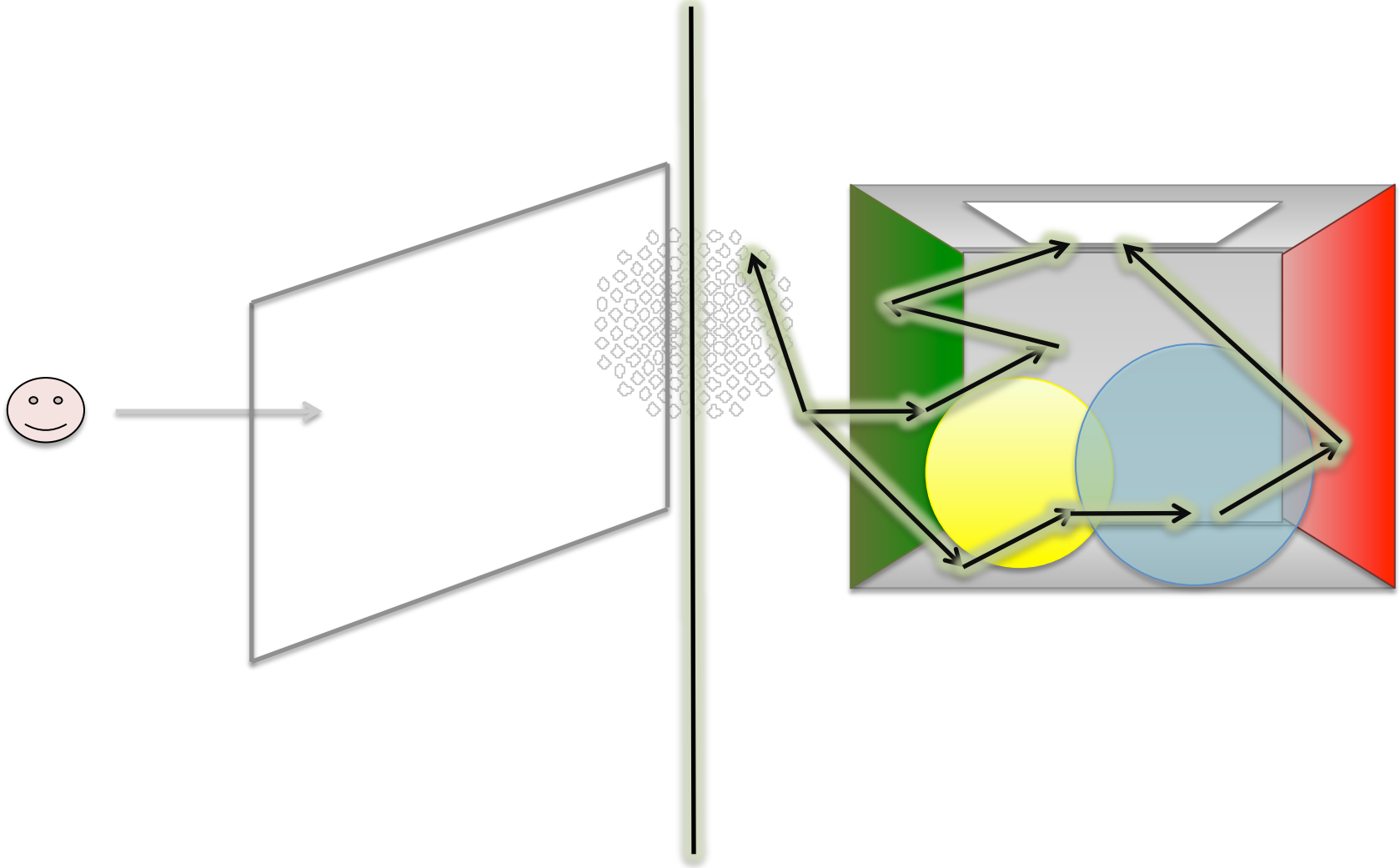
Visionaray

Scope

- Visionaray is a “Ray Tracing Template Library” providing algorithms and data structures that are related to ray tracing
- Focus on real-time and VR, but not necessarily so
- In contrast to competitors (e.g. Intel Embree), we provide facilities for all kinds of ray tracing related tasks:
  - Custom geometric primitives (not just triangles)
  - SIMD packet traversal
  - Texture filtering (CPU and GPU, higher-order)
  - BVH traversal (not just triangles, but any user primitive)

Visionaray Basics

Schedulers and Kernels



Visionaray Basics

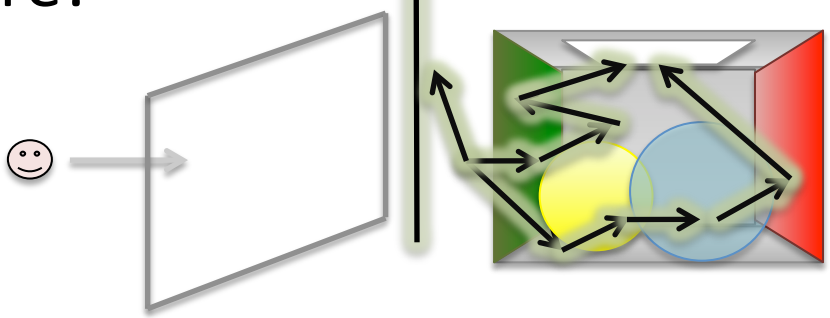
Schedulers and Kernels

Schedulers

- Primary ray generation in parallel
- Store final pixel color
- Independent of the algorithm!
- Run any algorithm on any hardware!

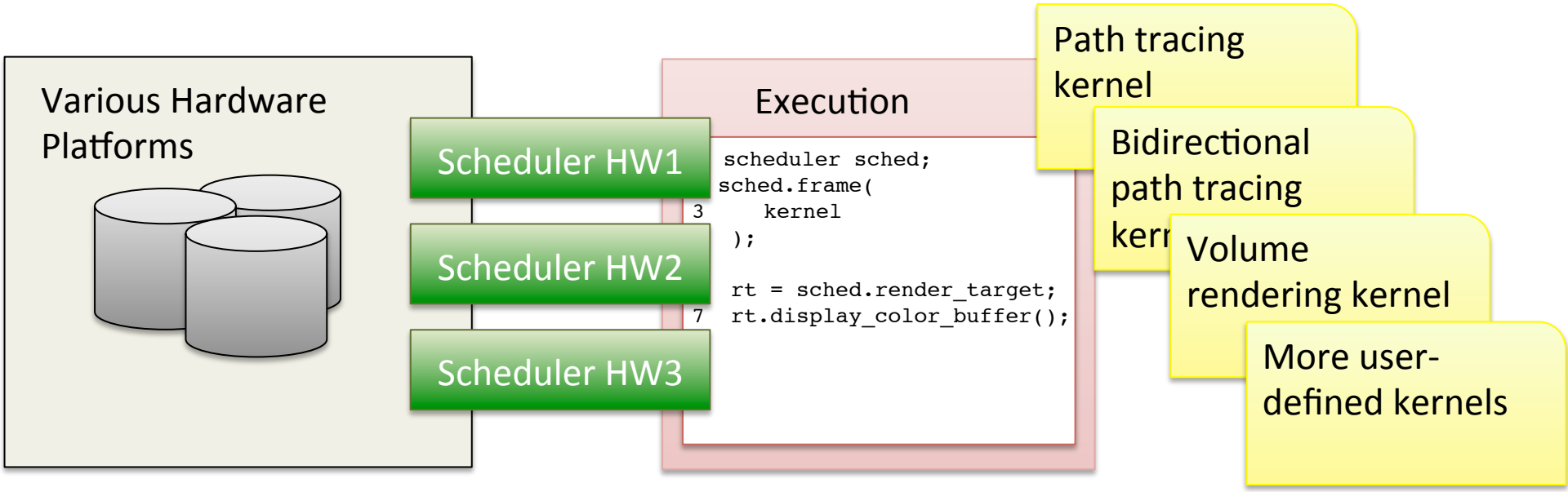
Kernels

- "Algorithmic phase", most often described in terms of single rays
- Similar basic functions:
  - Texture access
  - Primitive traversal
  - …



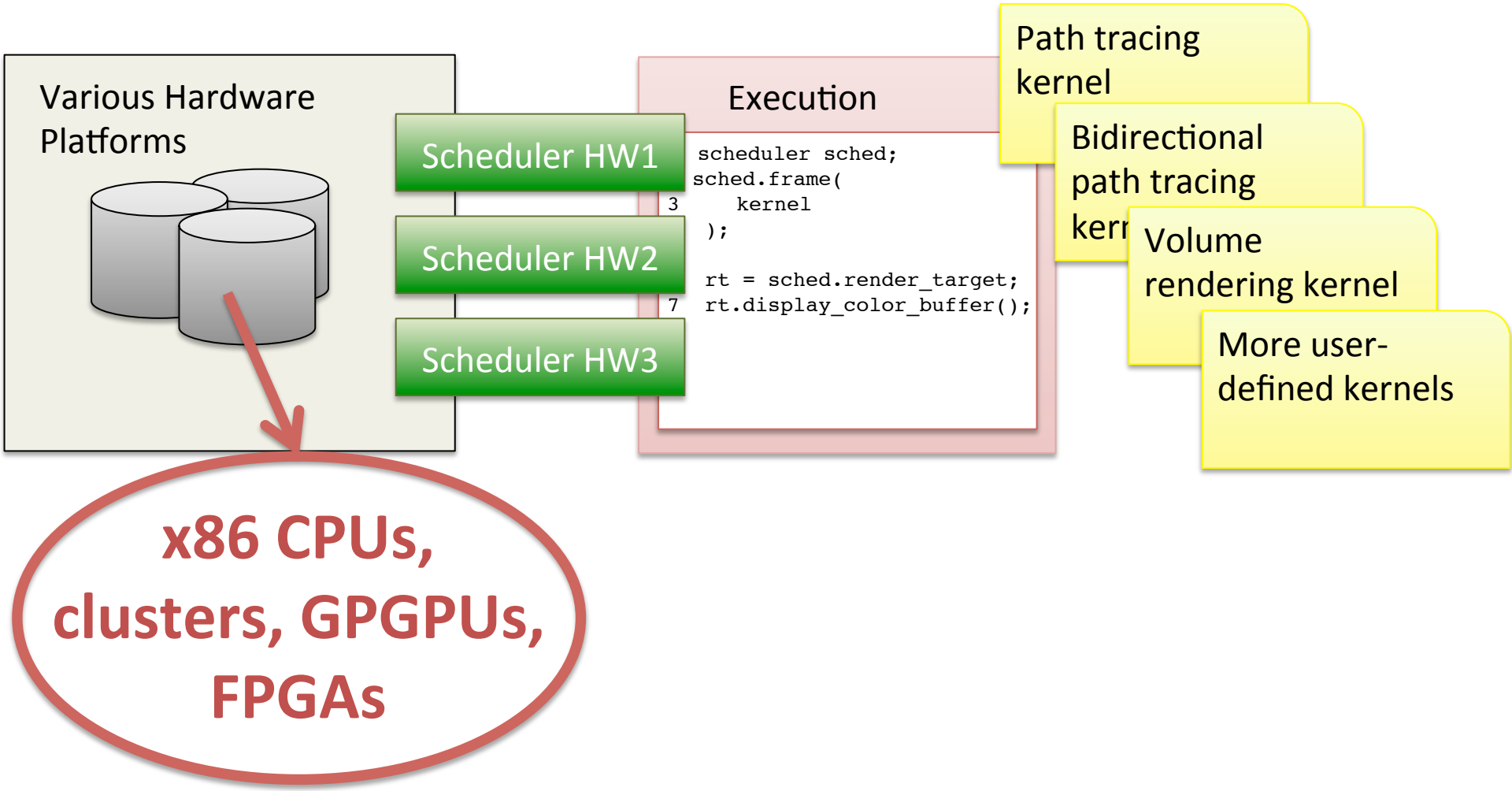
Visionaray Basics

Schedulers and Kernels



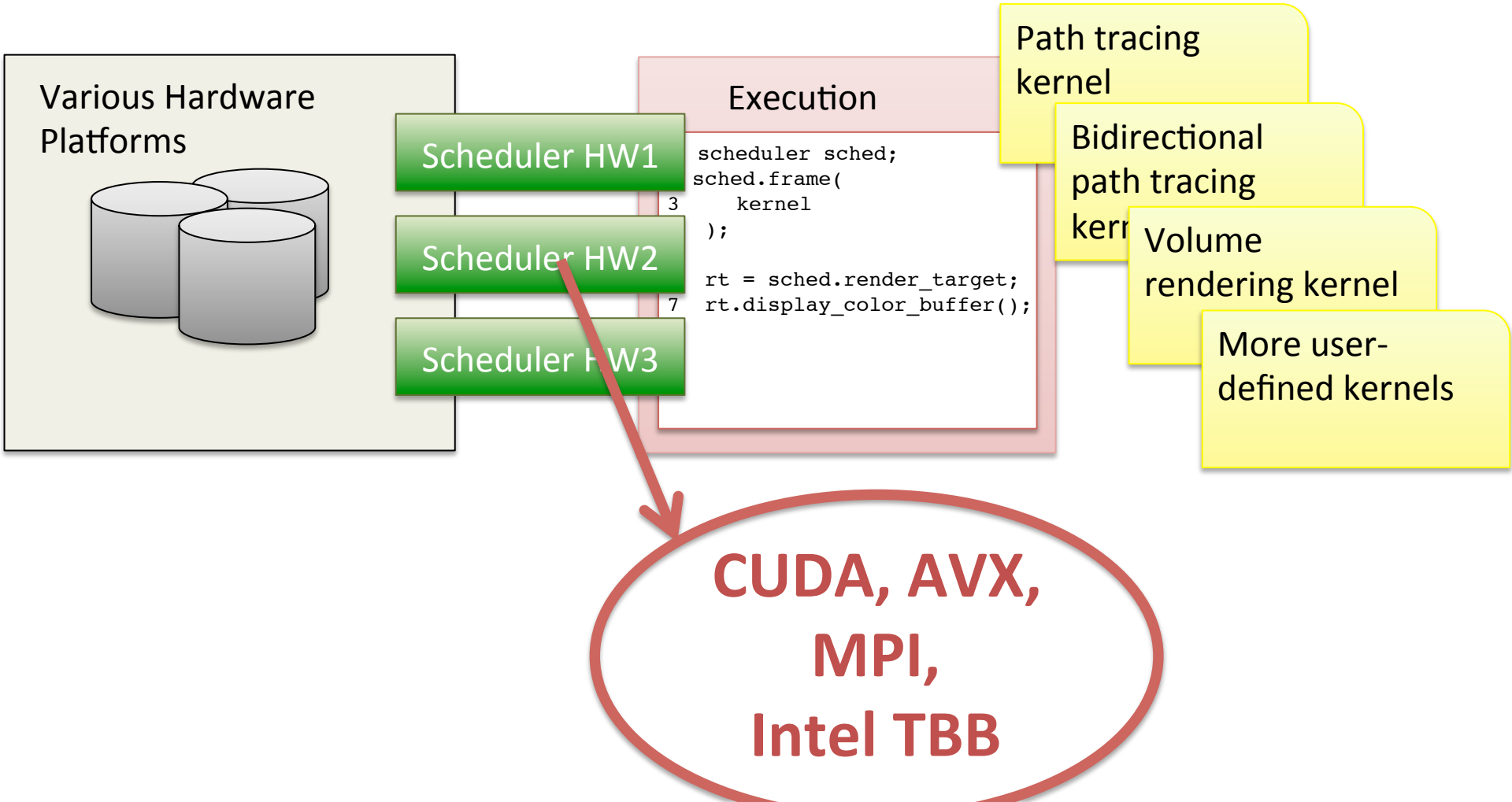
Visionaray Basics

Schedulers and Kernels



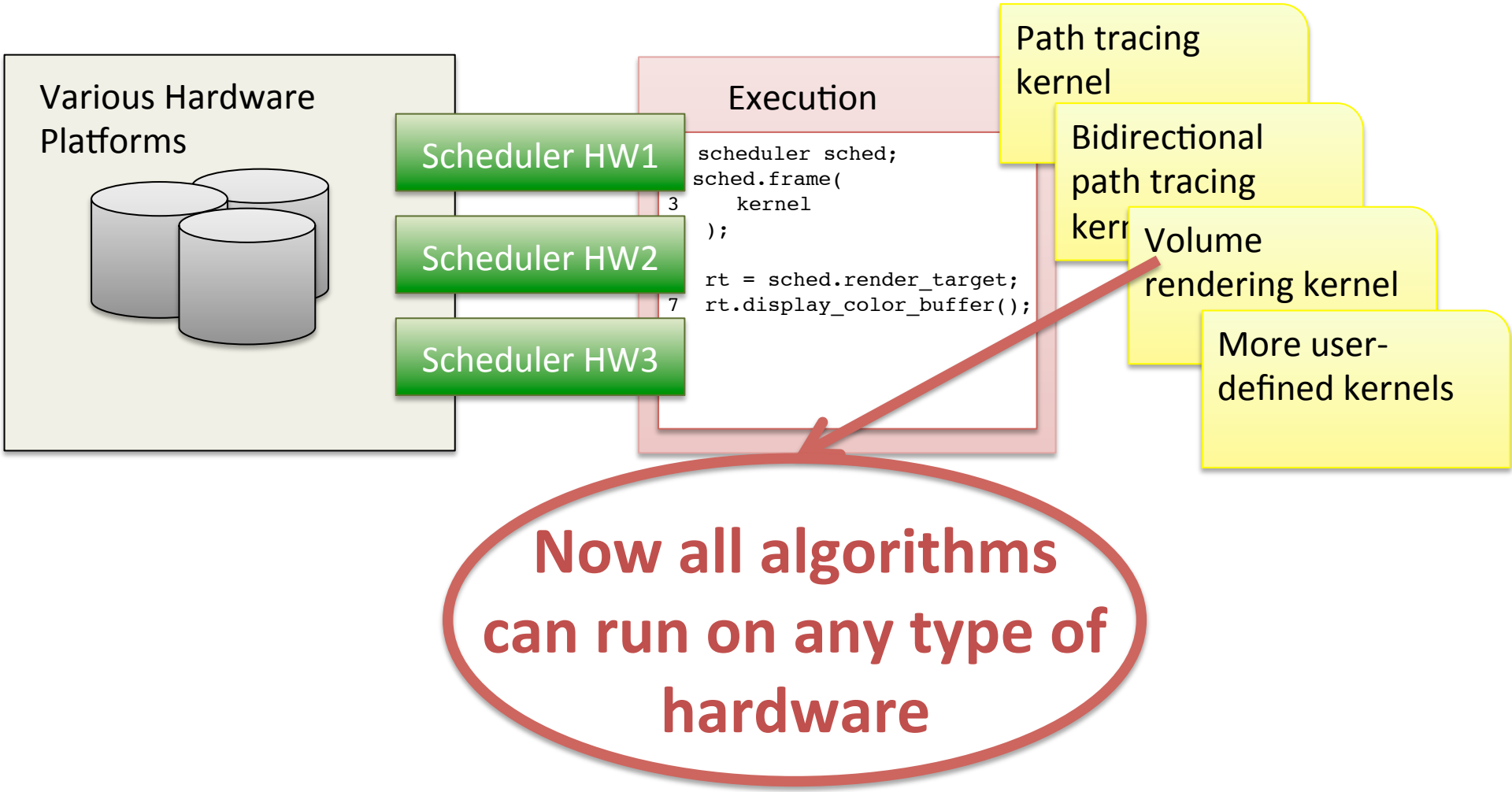
Visionaray Basics

Schedulers and Kernels



Visionaray Basics

Schedulers and Kernels



Visionaray Example

Ray Tracing Hello World ☺

```
#include <visionaray/camera.h>
#include <visionaray/scheduler.h>

using namespace visionaray;

typedef basic_ray<float>          ray_type;
typedef simple_sched<ray_type>    sched_type;
typedef vector<4, float>          color_type;

sched_type sched;
auto sparams = make_sched_params(
    camera,
    render_target
    );

sched.frame([=](ray_type r) -> color_type
{
    return color_type(1.0, 1.0, 1.0, 1.0);
},
sparams);
```

Visionaray Example

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},
sparams);
```

All basic types are templates (e.g. for SIMD)

Visionaray Example

Ray Tracing Hello World ☺

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sched.frame([=](ray_type r) -> color_type
{
    return color_type(1.0, 1.0, 1.0, 1.0);
},
sparams);
```

"simple_sched" is the most basic scheduler

Visionaray Example

Ray Tracing Hello World ☺

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using namespace visionaray;

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```

Create a scheduler instance

Visionaray Example

Ray Tracing Hello World ☺

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sched.frame([=](ray_type r) -> color_type
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    return color_type(1.0, 1.0, 1.0, 1.0);
},
sparams);
```

Create a scheduler instance

Camera just like in OpenGL

Visionaray Example

Ray Tracing Hello World ☺

```
#include <visionaray/camera.h>
#include <visionaray/scheduler.h>

using namespace visionaray;

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{
    return color_type(1.0, 1.0, 1.0, 1.0);
},
sparams);
```

Create a scheduler instance

Rendertarget: framebuffer

Visionaray Example

Ray Tracing Hello World ☺

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#include <visionaray/scheduler.h>

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    );

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{
    return color_type(1.0, 1.0, 1.0, 1.0);
},
sparams);
```

Most simple Visionaray kernel

Visionaray Example

Ray Tracing Hello World ☺

```
#include <visionaray/camera.h>
#include <visionaray/scheduler.h>

using namespace visionaray;

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    render_target
    );

sched.frame([=](ray_type r) -> color_type
{
    return color_type(1.0, 1.0, 1.0, 1.0);
},
sparams);
```

Lambda passed to sched's frame()

Visionaray Example

Ray Tracing Hello World ☺

```
#include <visionaray/camera.h>
#include <visionaray/scheduler.h>

using namespace visionaray;

typedef basic_ray<float> ray_type;
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typedef vector<4, float> color_type;

sched_type sched;
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    render_target
    );

sched.frame([=](ray_type r) -> color_type
{
    return color_type(1.0, 1.0, 1.0, 1.0);
},
sparams);
```

Primary ray passed to the kernel

Visionaray Example

Ray Tracing Hello World ☺

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#include <visionaray/scheduler.h>

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    );

sched.frame([=](ray_type r) -> color_type
{
    return color_type(1.0, 1.0, 1.0, 1.0);
},
sparams);
```

Returns a color

Visionaray built-in types

Schedulers and Kernels

- Built-in schedulers at your convenience:
  - simple_sched (pure scanlines, no multi-threading)
  - tiled_sched (task queue-based with atomics)
  - cuda_sched
  - sycl_sched (w.i.p.)
  - mpi_sched (w.i.p.)
- Built-in kernels
  - “Simple”: primary visibility only
  - “Whitted”: perfect reflections and hard shadows
  - “Pathtracing”: basic path tracer

Visionaray built-in types

Schedulers and Kernels

- We expect 3 types of framework users:
  - Reuse existing algorithms but implement e.g. custom primitives (e.g. Bezier Patches, Nurbs, …) or custom texturing algorithms
  - Reuse existing schedulers, write completely new kernels (immediately available on a variety of platforms)
  - Port existing algorithm (i.e. kernel) to new platform: write a new scheduler (hard task, might involve adaptation of intrinsic functions (which are all templates, anyway ☺))

Visionaray built-in types

Geometric Primitives

- Built-in kernels deal with surfaces
  - (Your own kernels need not to!)
- Everything is a template, so:
  - Triangles and spheres are implemented
  - But just implement your own ones. Built-in kernels (basically) cope with any primitive that implements `intersect(ray, primitive)`
  - No virtual inheritance w/ templates ➔ for multiple primitives use variants instead ("tagged unions")
    - This is highly efficient because for pure triangle ray tracing no switch-case/vtable lookup necessary in the inner loop

Visionaray built-in types

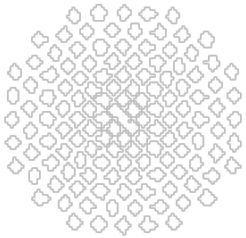
Single Primitives Example

```
typedef basic_triangle<3, float> triangle_t;

std::vector<triangle_t> triangles;
for (int i=0; i<count; ++i) triangles.emplace_back(v1, e1, e2);

auto kparams = make_kernel_params(
    triangles.data(),                    // begin iterator
    triangles.data() + triangles.size(), // end iterator
    /* more parameters here, like normals or textures */
    );

whitted::kernel<decltype(kparams)> kernel;
kernel.params = kparams;

sched.frame(kernel, sparams);
```

Visionaray built-in types

Generic Primitives Example

```
typedef basic_triangle<3, float> triangle_t;
typedef basic_sphere<float>      sphere_t;
typedef basic_myown<float>       myown_t;


typedef generic_primitive<
    triangle_t,
    sphere_t,
    myown_t
    >          primitive_t;
```



Visionaray built-in types

Generic Primitives Example

```
typedef basic_triangle<3, float> triangle_t;
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typedef basic_myown<float>       myown_t;


typedef generic_primitive<
    triangle_t,
    sphere_t,
    myown_t
    >           primitive_t;
```

Now use primitive_t just like in the example before!

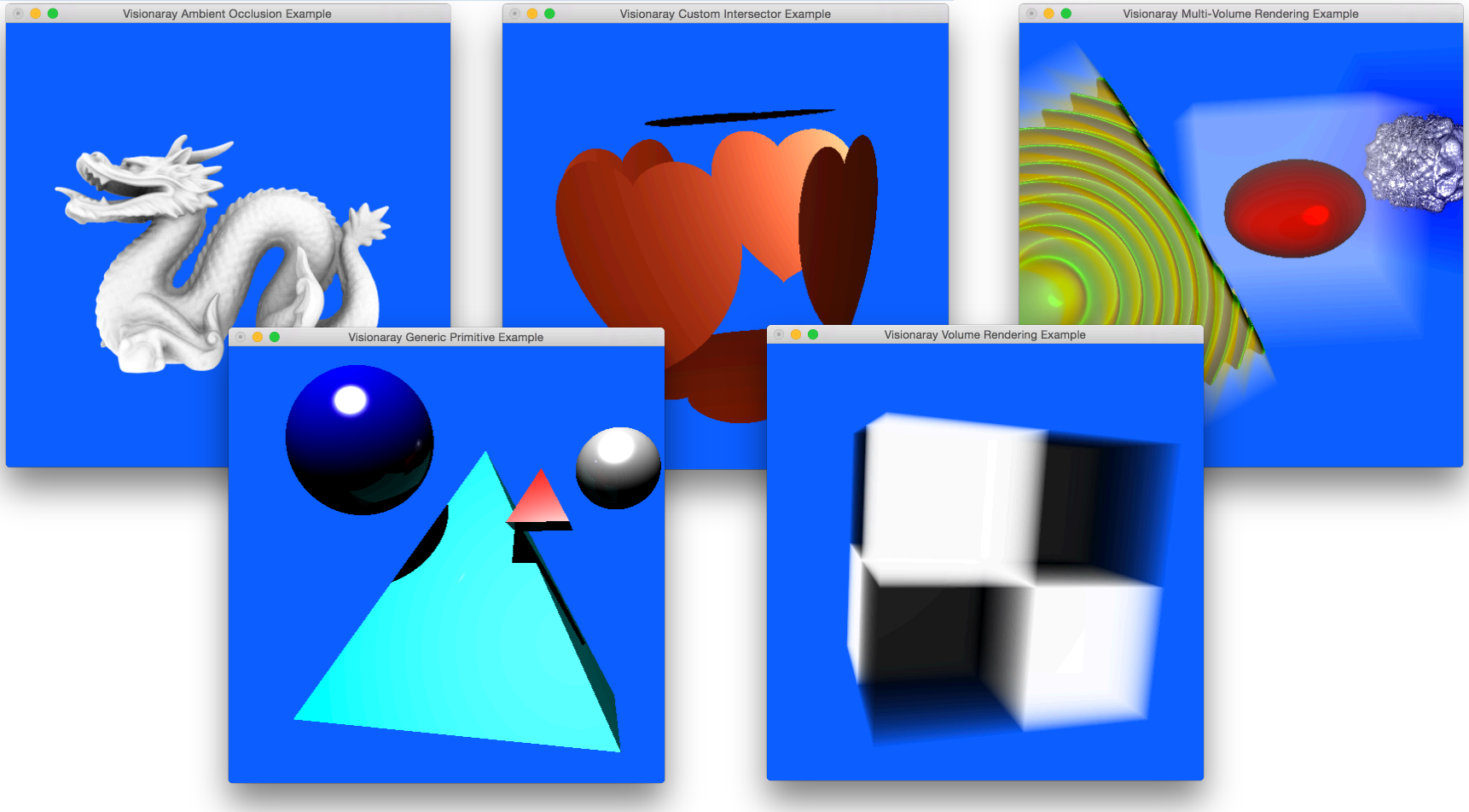
Visionaray built-in types

Single Primitives Example

```
typedef ... primitive_t;

std::vector<primitive_t> primitives;
for (int i=0; i<count; ++i) primitives.emplace_back(...);

auto kparams = make_kernel_params(
    primitives.data(),                    // begin iterator
    primitives.data() + primitives.size(),// end iterator
    /* more parameters here, like normals or textures */
    );

whitted::kernel<decltype(kparams)> kernel;
kernel.params = kparams;

sched.frame(kernel, sparams);
```

Example Programs on Github

Demonstrate How to Use All This!

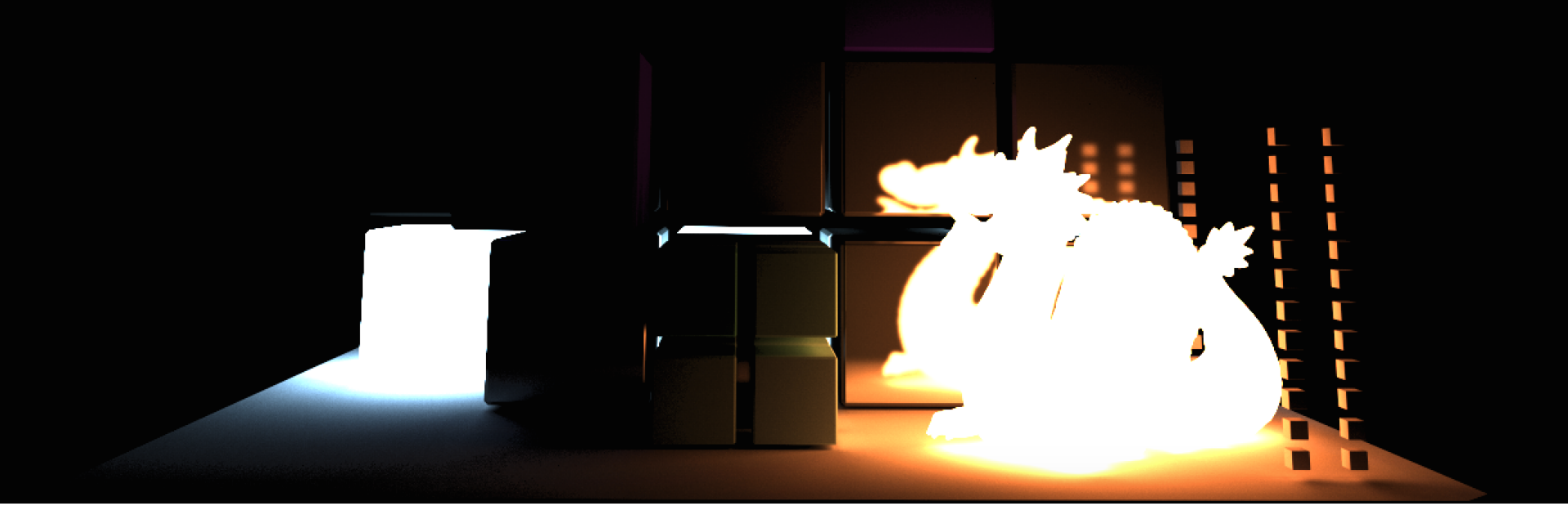


https://github.com/szellmann/visionaray

Virtual Reality

Plugin in for OpenCOVER

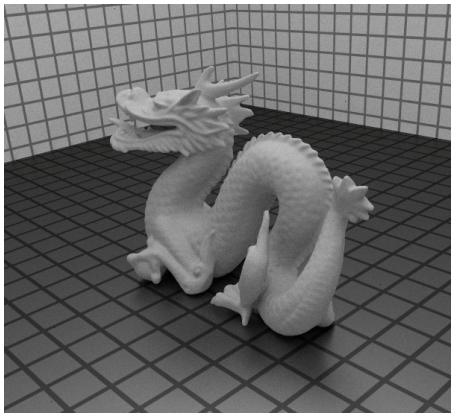
- Virtual environments
- Head tracking
- Scene graph rendering
- Walk-in immersive environments (“CAVE”)



Questions?

https://github.com/szellmann/visionaray

https://github.com/hlrs-vis/covise



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zellmann(at)uni-koeln.de