CUDA® C++ in Jupyter: Adding CUDA Runtime Support to Cling

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[2] Lawrence Berkeley National Laboratory, USA

NVIDIA GPU Technology Conference 2020

San Jose, March 26th 2020

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Novel Particle Accelerator Research

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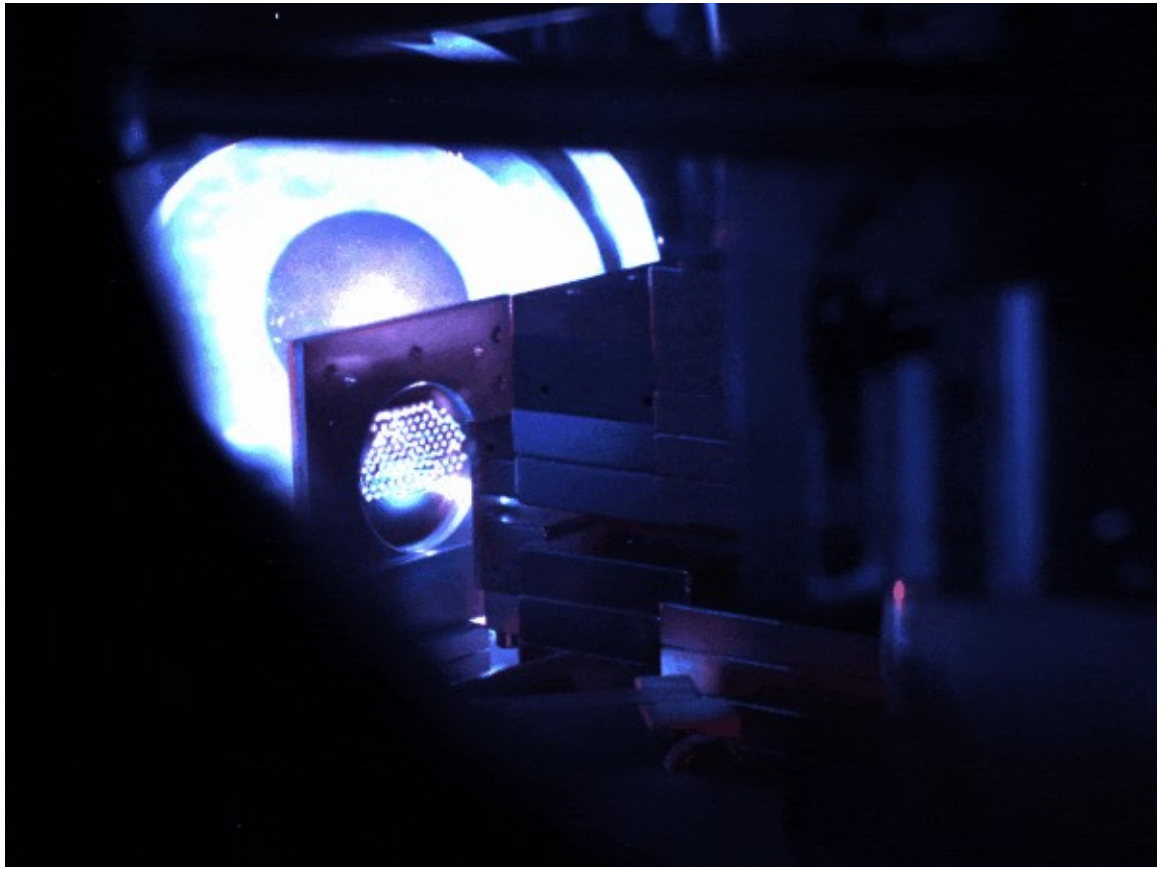

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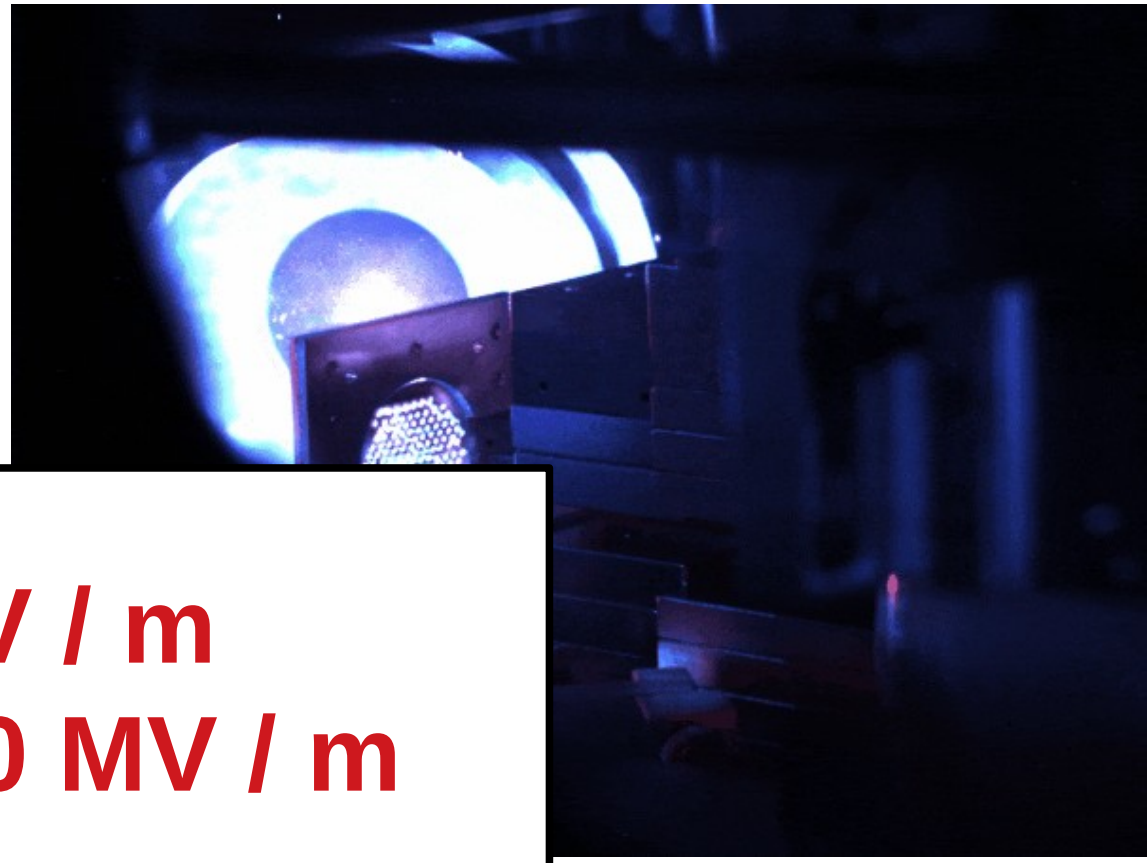

~100 MV / m

→ 1 000 000 MV / m

Laser-Plasma Simulations

Modeling Matter under Extreme Conditions

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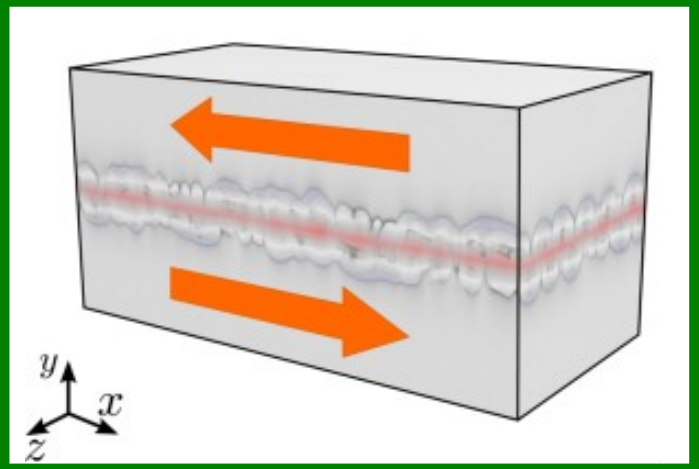
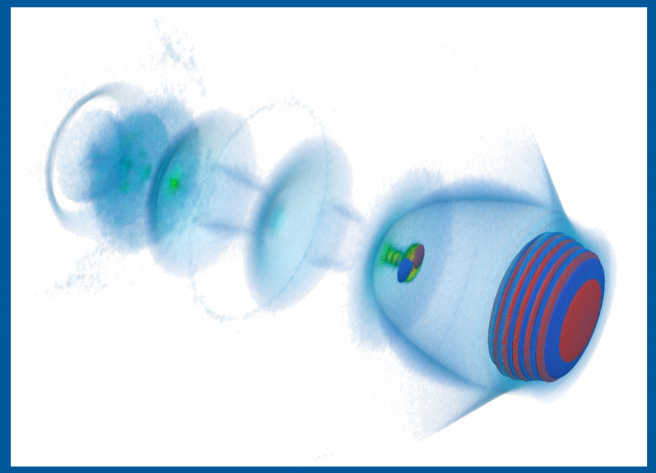
Astrophysics in the Lab

- Astrophysics
- Plasma instabilities



Novel Particle Accelerators

- Compact X-ray, electron and ion beam sources
- Pushing the Energy Frontier
- Matter at extreme conditions



Massively Parallel HPC

- Leadership-scale supercomputing
- Novel algorithms

69 PFlop/s (SP)

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Data Driven Science at Exascale

The Widening Gap between Flop/s and I/O Bandwidth

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SYSTEM SPECS	TITAN	SUMMIT	FRONTIER
Peak Performance	27 PF	200 PF	> 1.5 EF
		1/3x	1/3x
Storage	32 PB, 1 TB/s, Lustre Filesystem	250 PB, 2.5 TB/s, GPFS™	2-4x performance and capacity of Summit's I/O subsystem. Frontier will have near node storage like Summit.

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In situ approaches: **tightly** versus **loosely** coupled workflows

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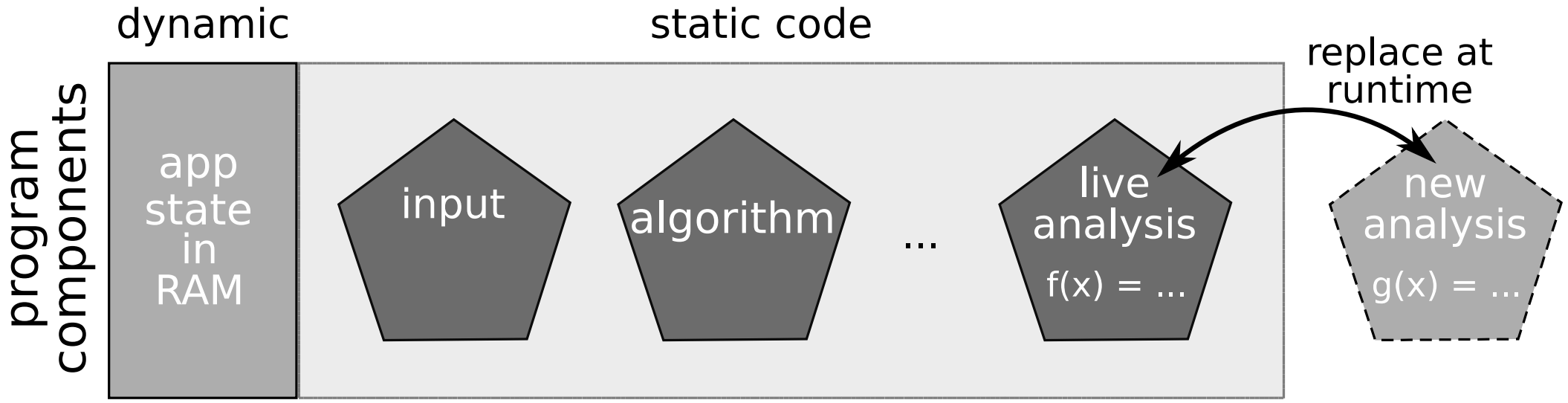
C++ *Feels* too Static

Data is Code is Data



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Interactive C++
An introduction to Cling

How to use Cling

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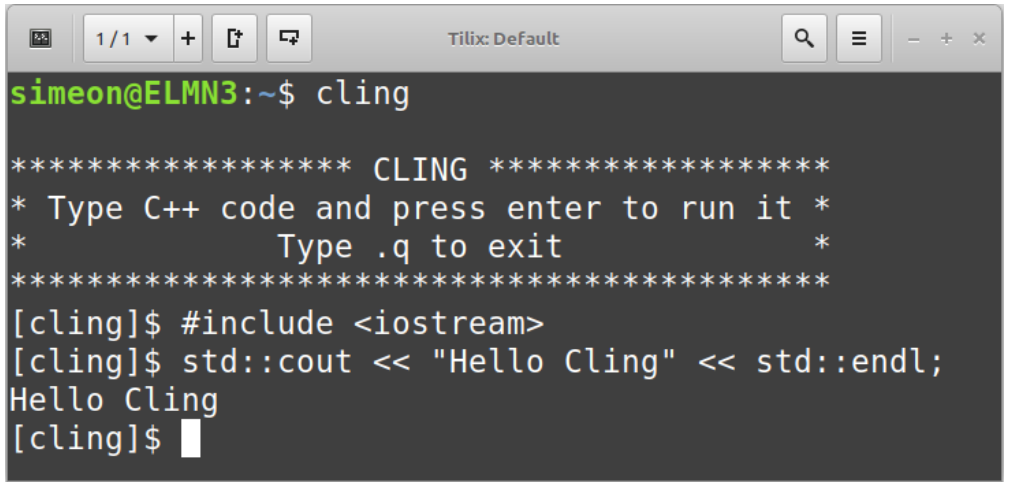
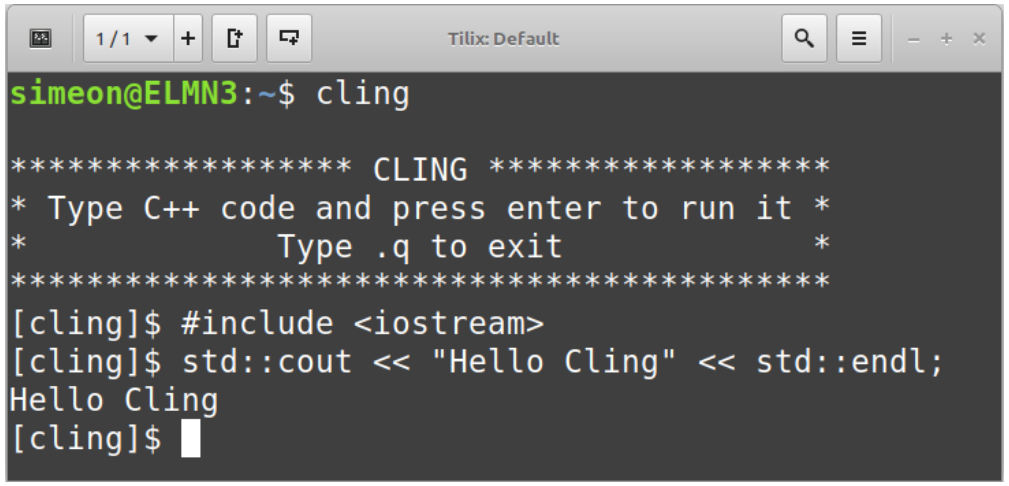


How to use Cling




```
#include "cling/Interpreter/Interpreter.h"

int main(int argc, char *argv){
      auto cling = cling::Interpreter(argc, argv);
      return 0;
}
```

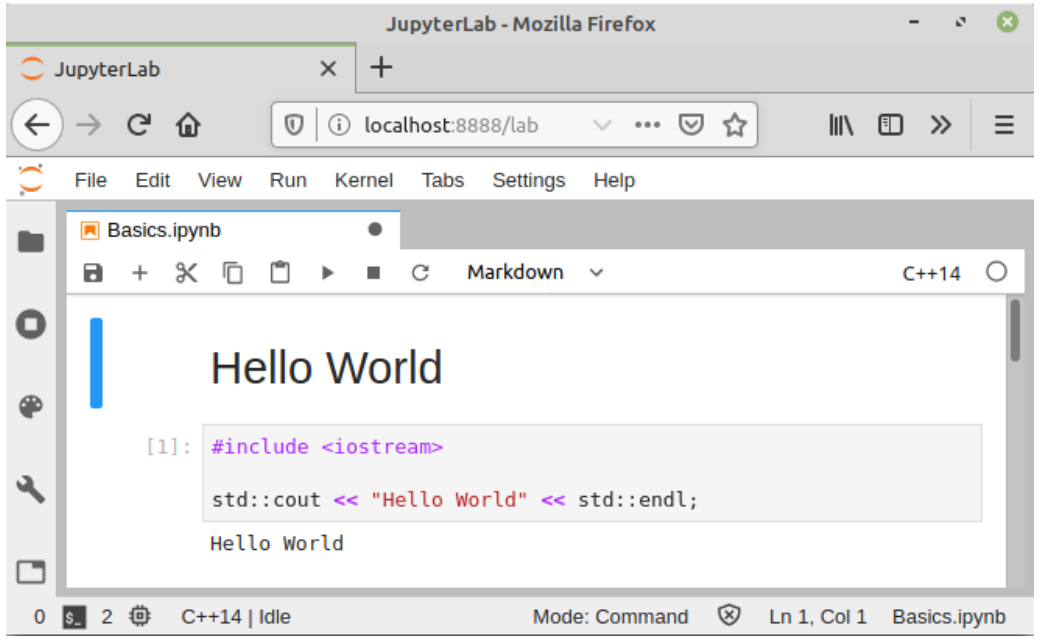
How to use Cling

```
simeon@ELMN3:~$ cling

****************** CLING ******************
* Type C++ code and press enter to run it *
*             Type .q to exit             *
*******************************************
[cling]$ #include <iostream>
[cling]$ std::cout << "Hello Cling" << std::endl;
Hello Cling
[cling]$
```

```
#include "cling/Interpreter/Interpreter.h"

int main(int argc, char *argv){
      auto cling = cling::Interpreter(argc, argv);
      return 0;
}
```



[Jupyter Live Demo]

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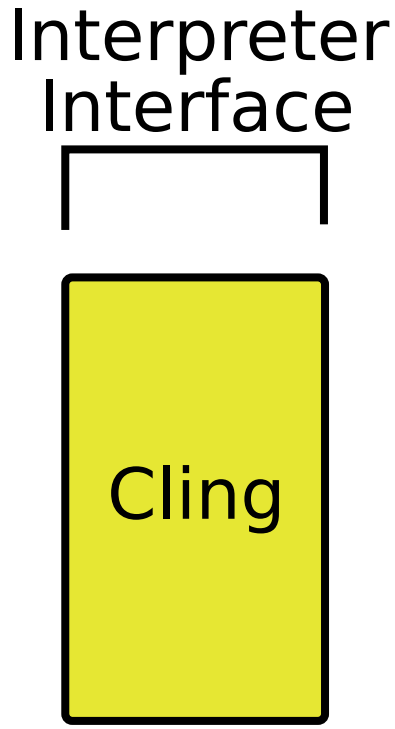
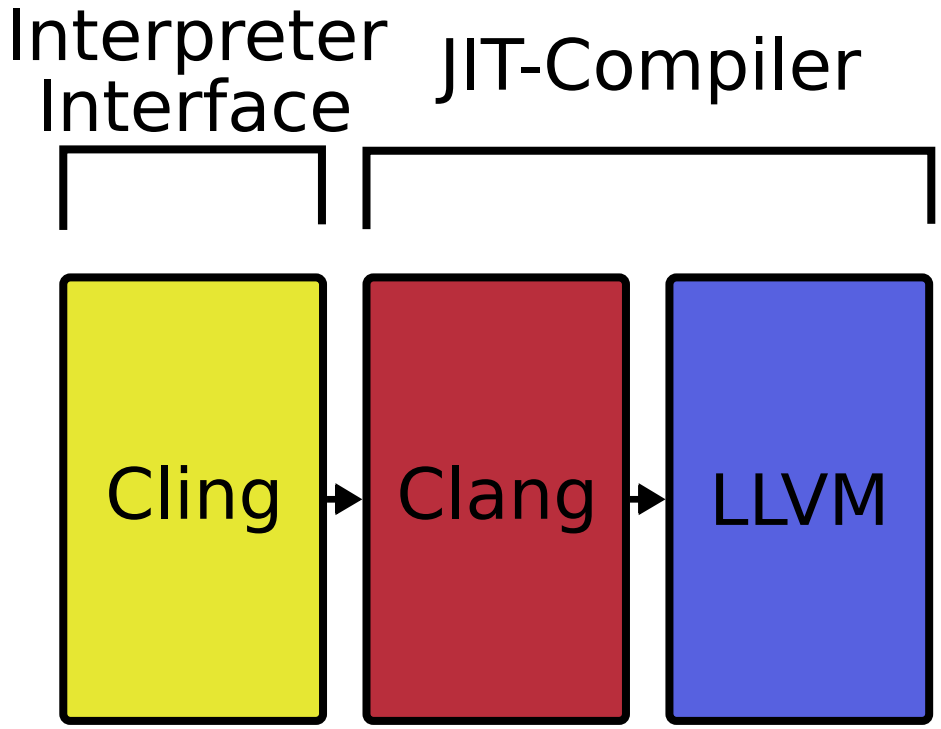
Architecture

Xeus-Cling Jupyter Architecture

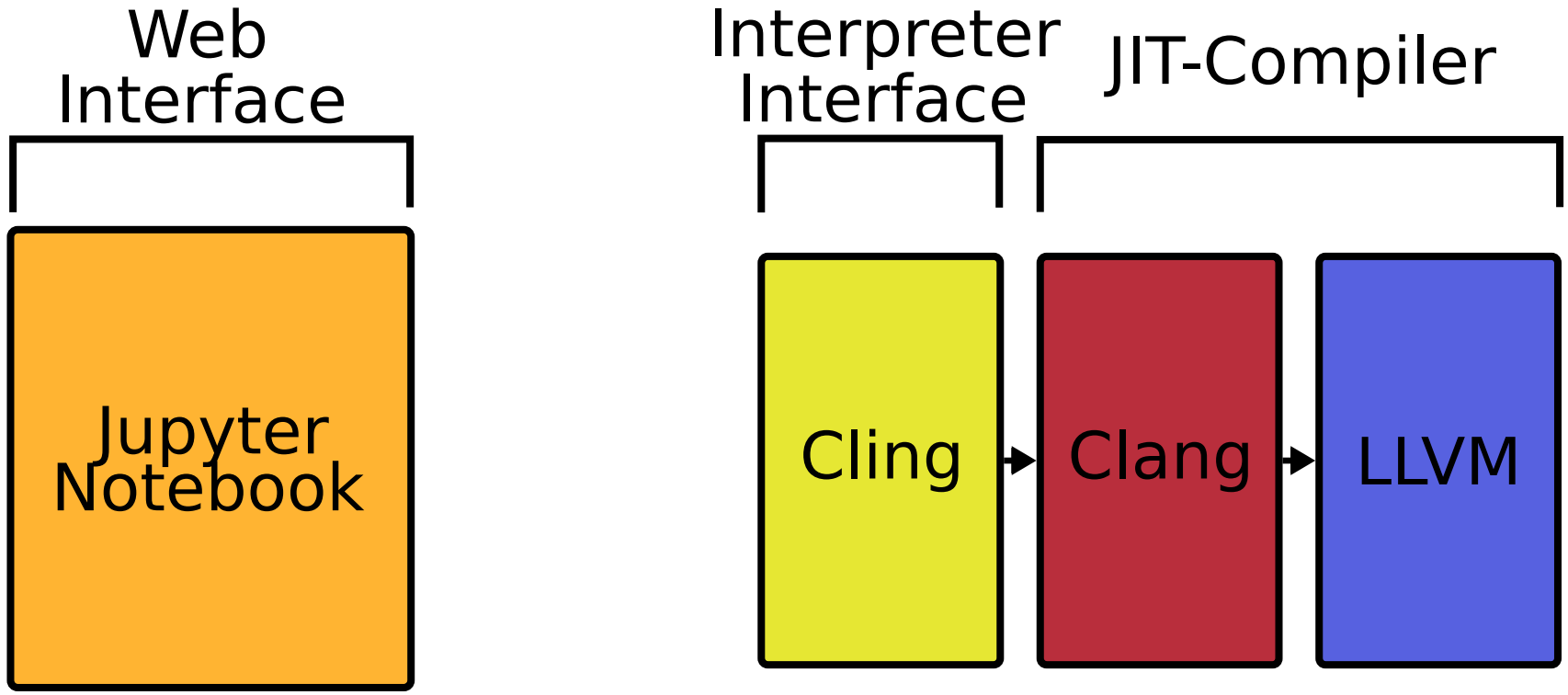
Xeus-Cling Jupyter Architecture



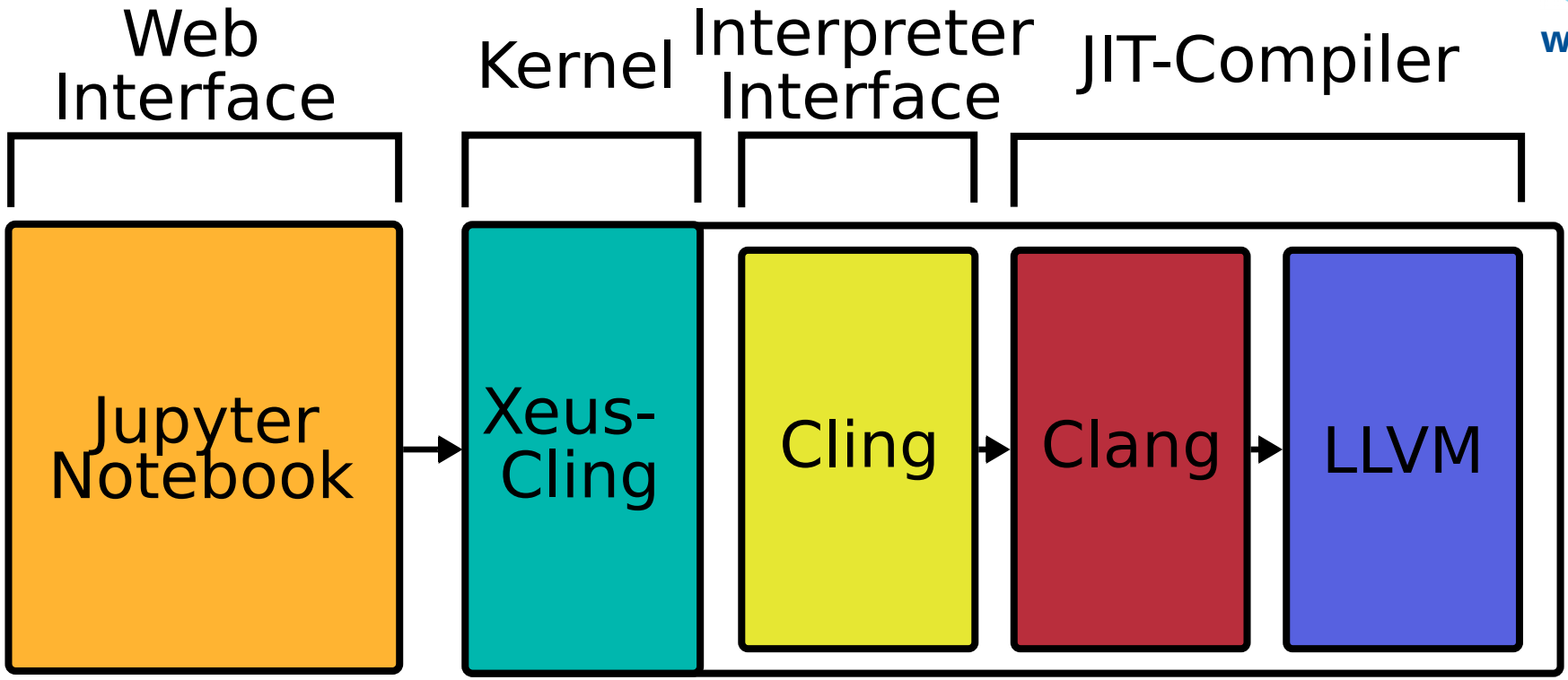
Xeus-Cling Jupyter Architecture



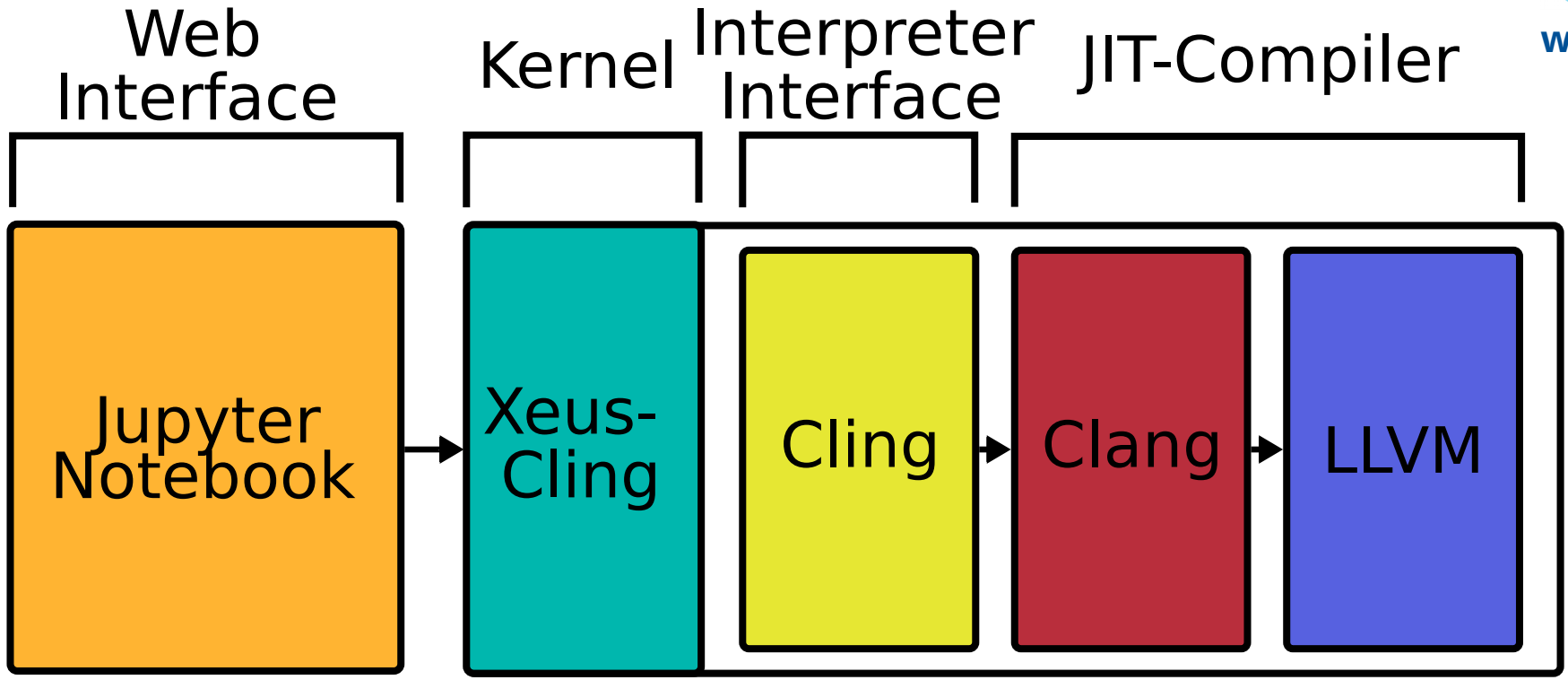
Xeus-Cling Jupyter Architecture



Xeus-Cling Jupyter Architecture



Xeus-Cling Jupyter Architecture



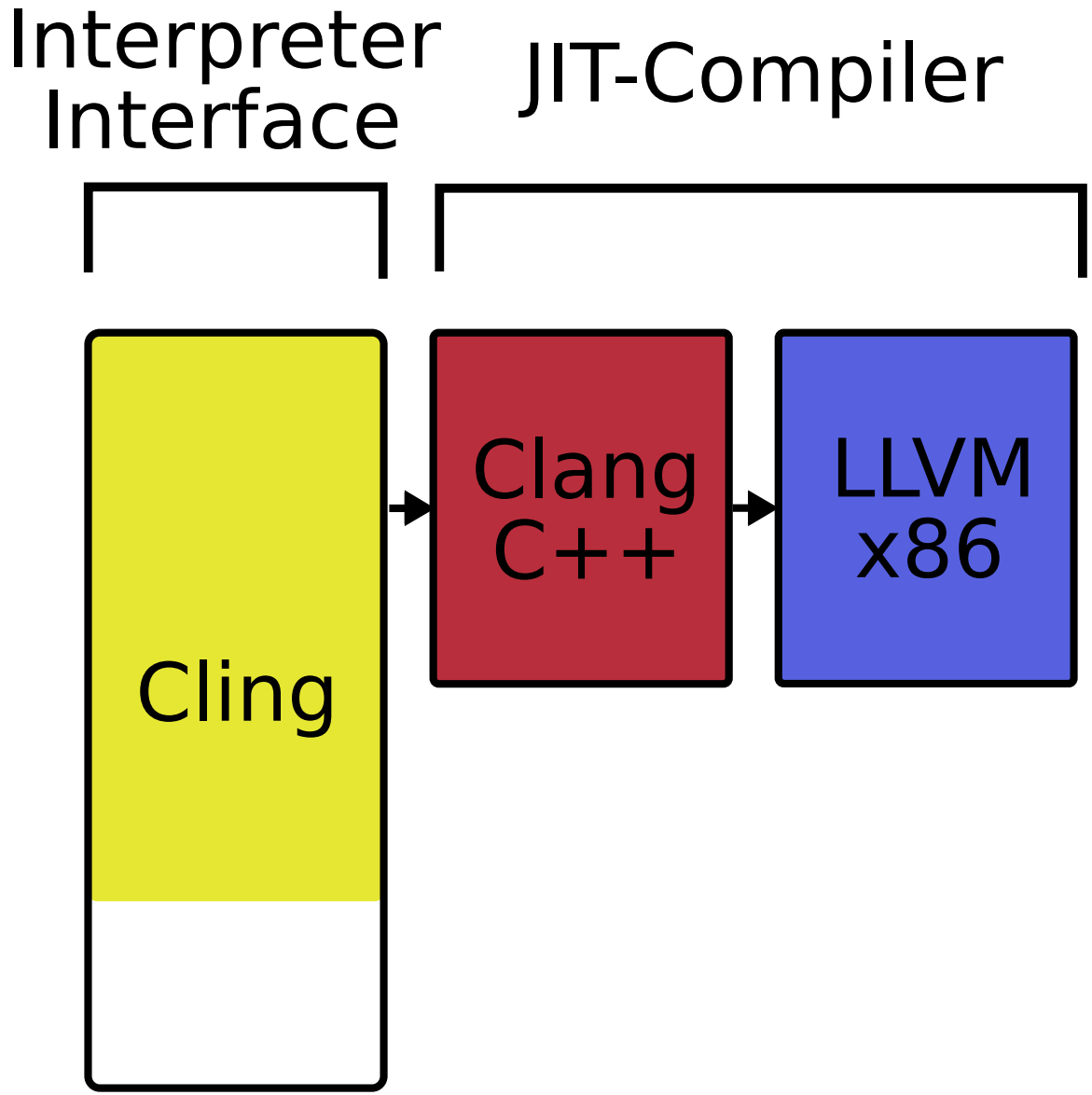
Jupyter

Quant-stack

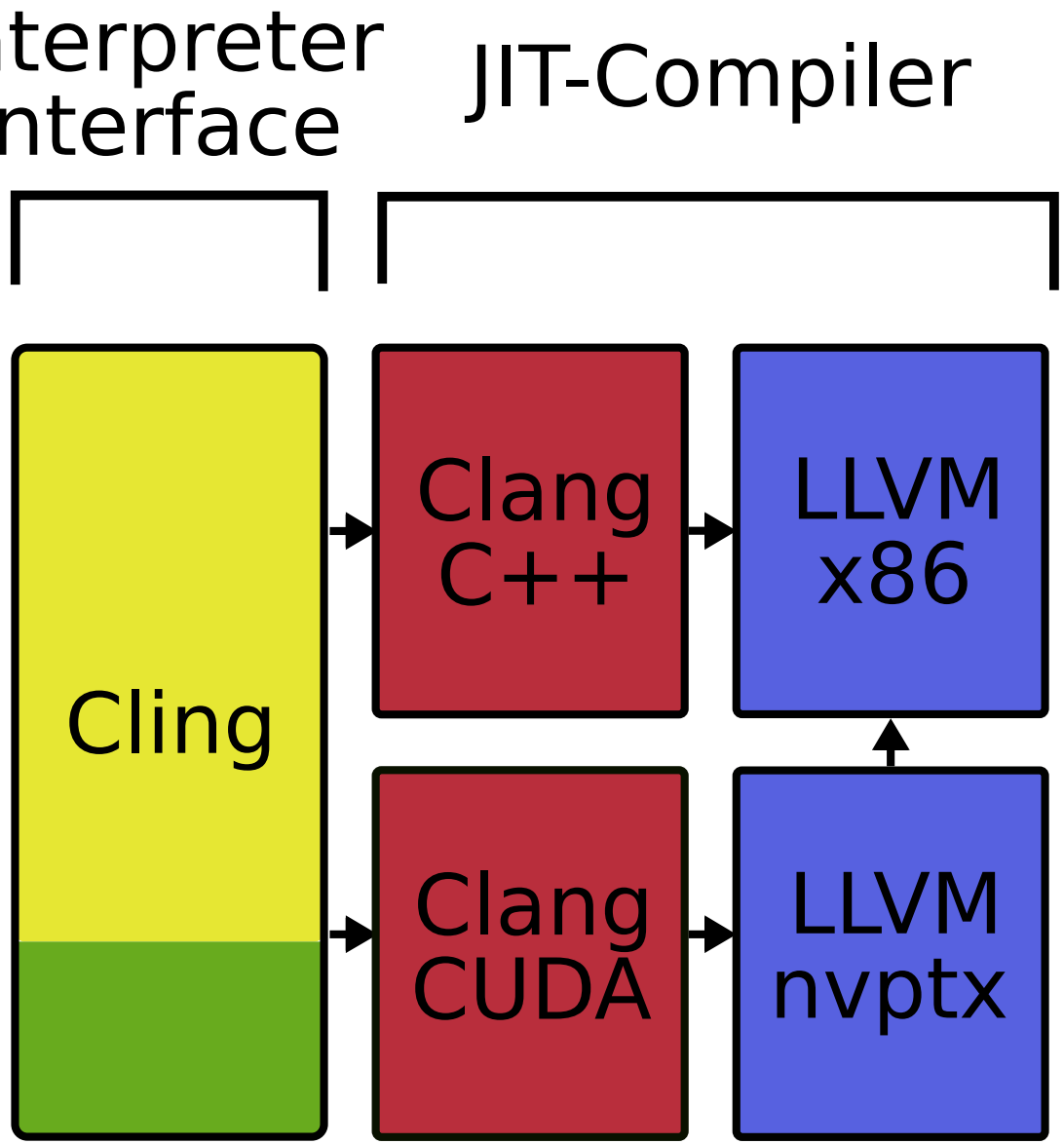
CERN

LLVM

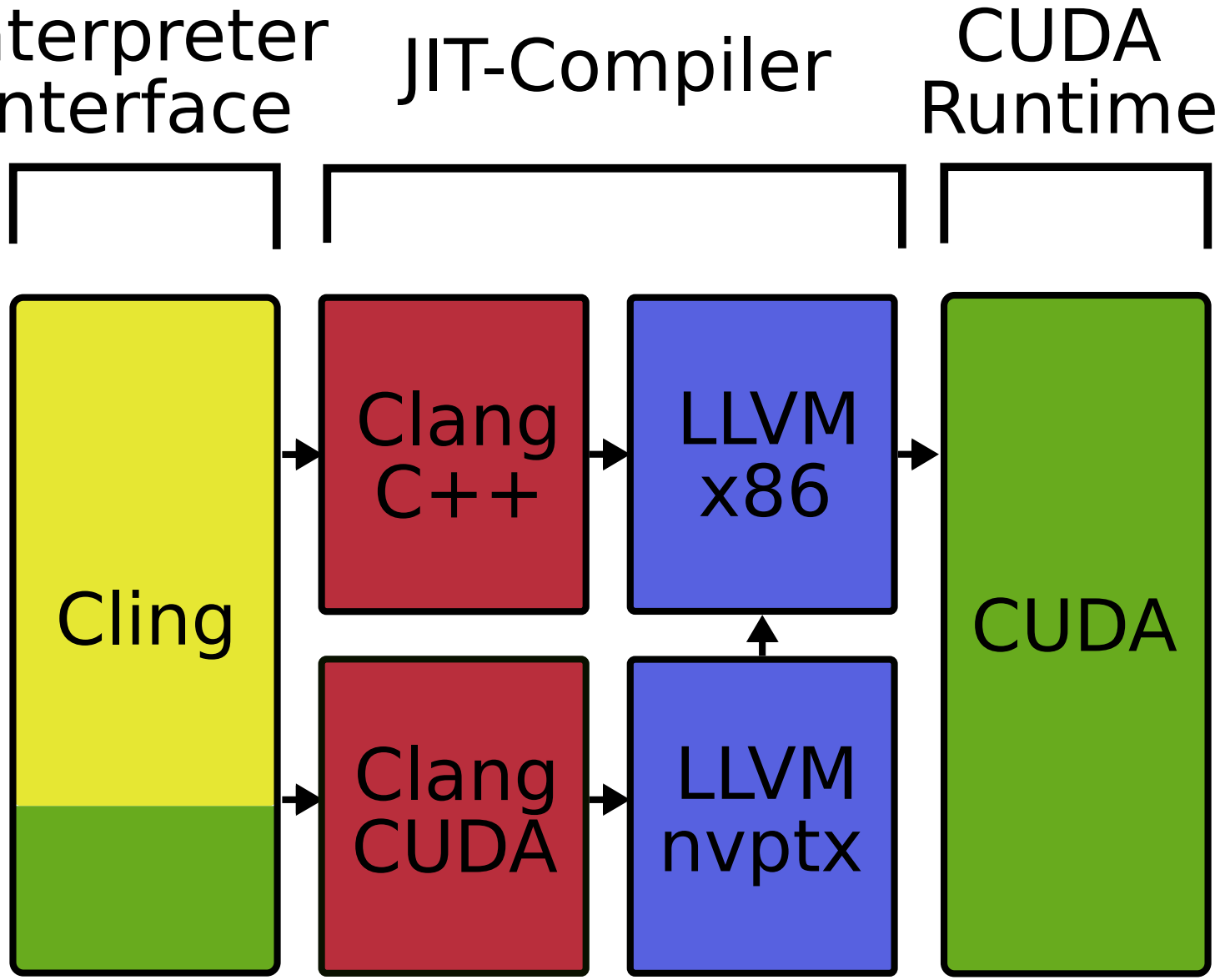
CUDA Extension



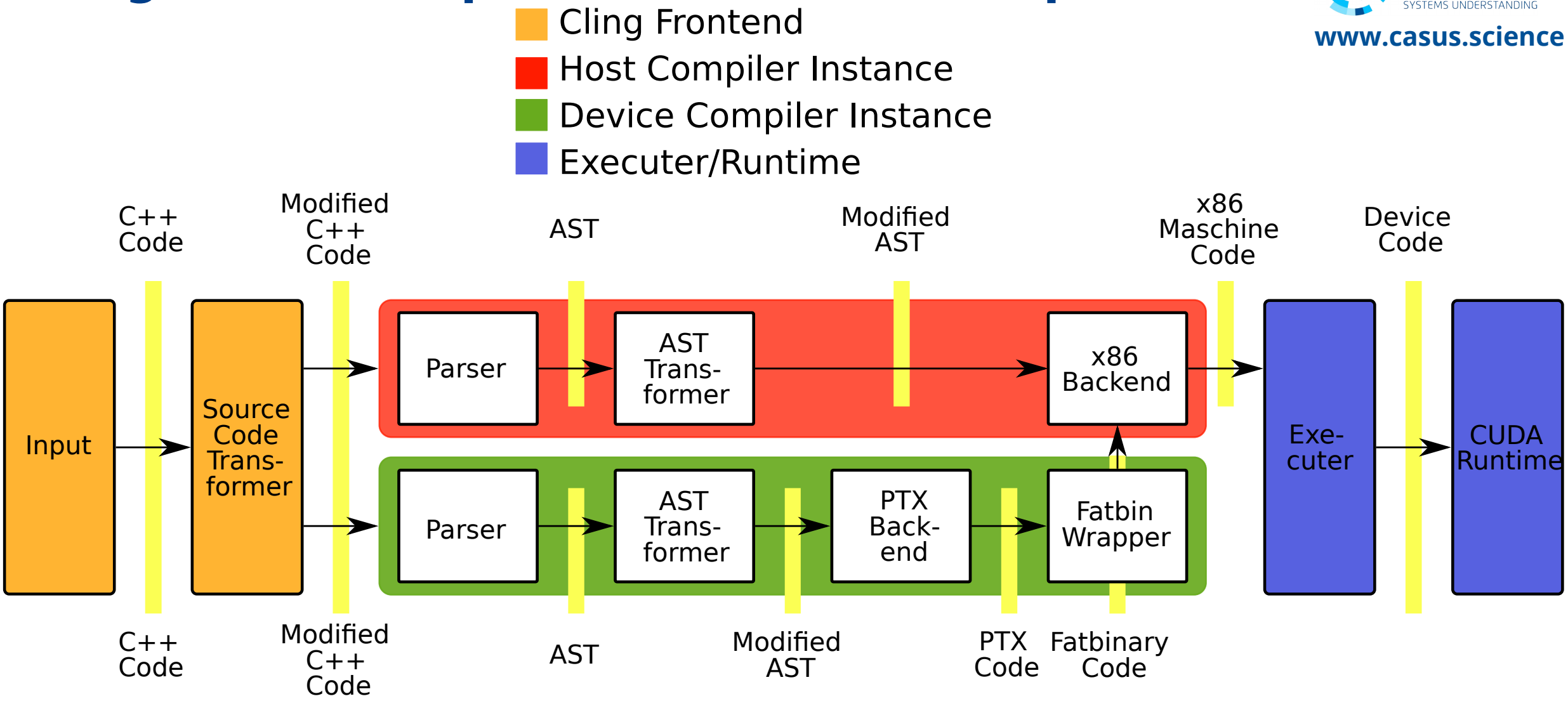
CUDA Extension



CUDA Extension



Cling-CUDA Compiler and Execution Pipeline



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Our Vision for Interactive, GPU-driven Supercomputing

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PIConGPU

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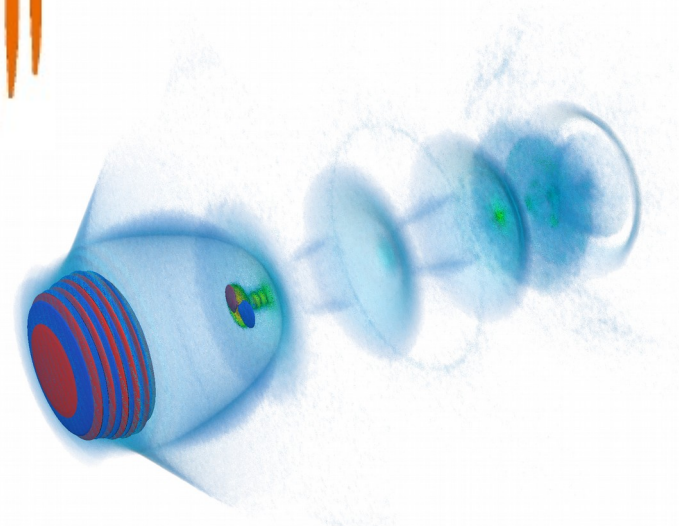

A. Huebl et al., ISC High Performance, pp. 15-29 (2017)
DOI:10.1007/978-3-319-67630-2_2

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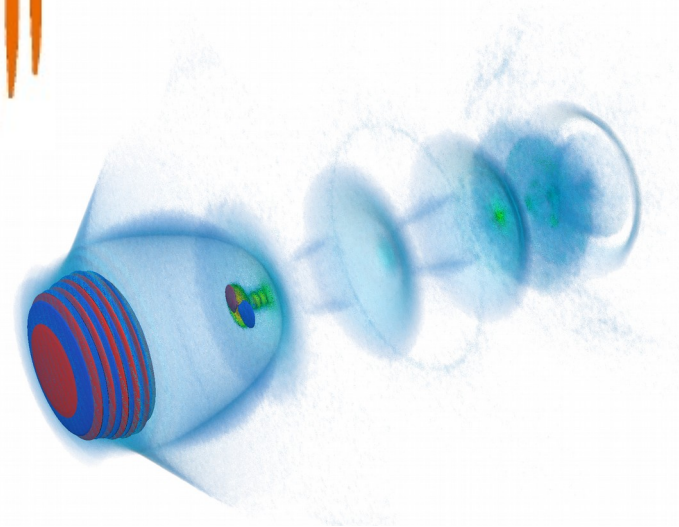

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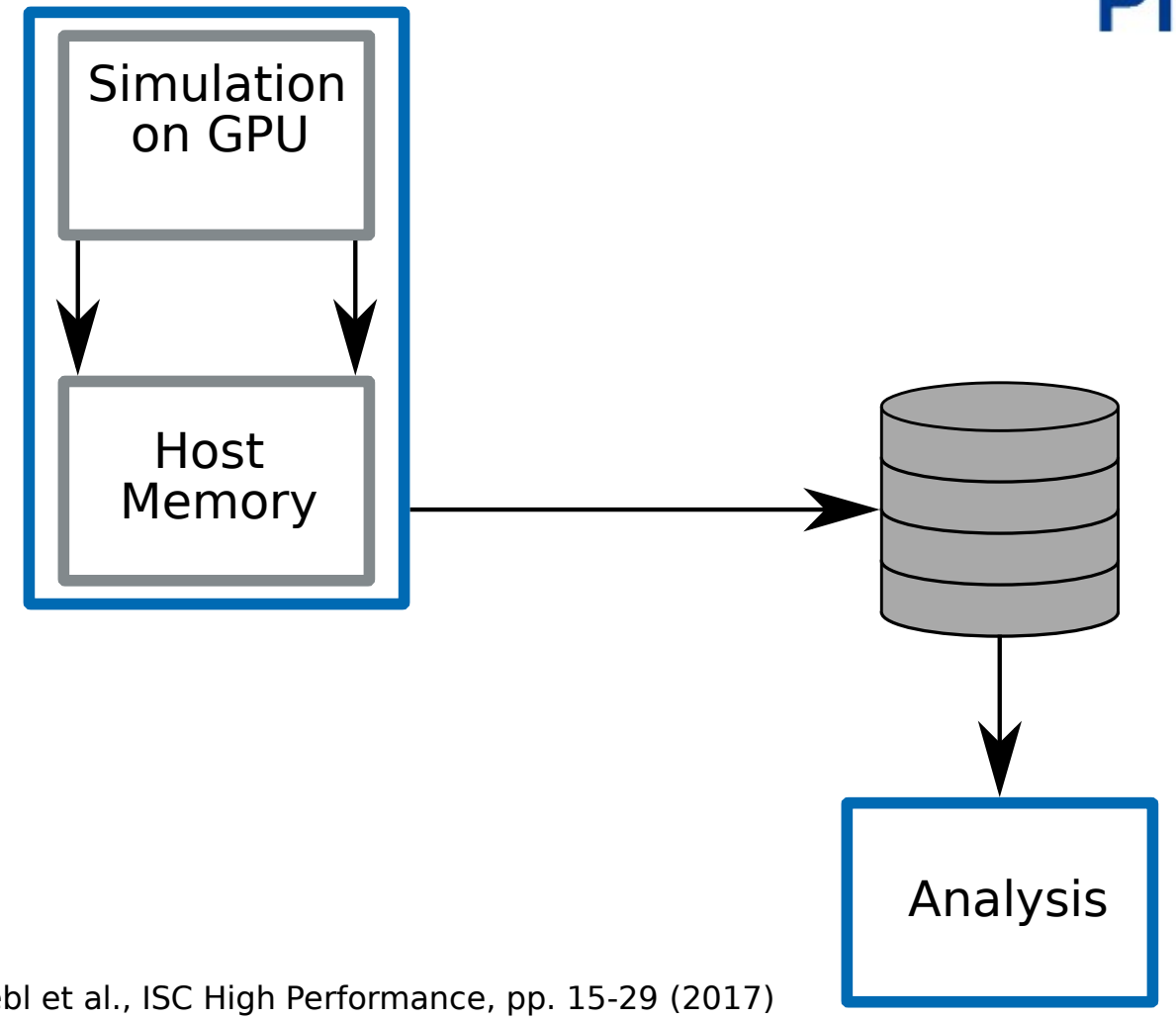

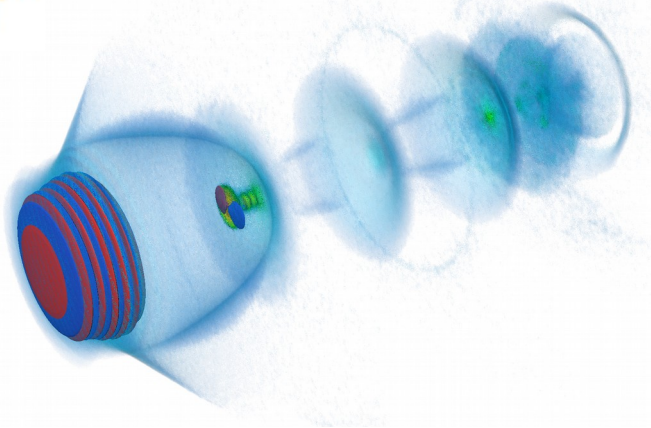

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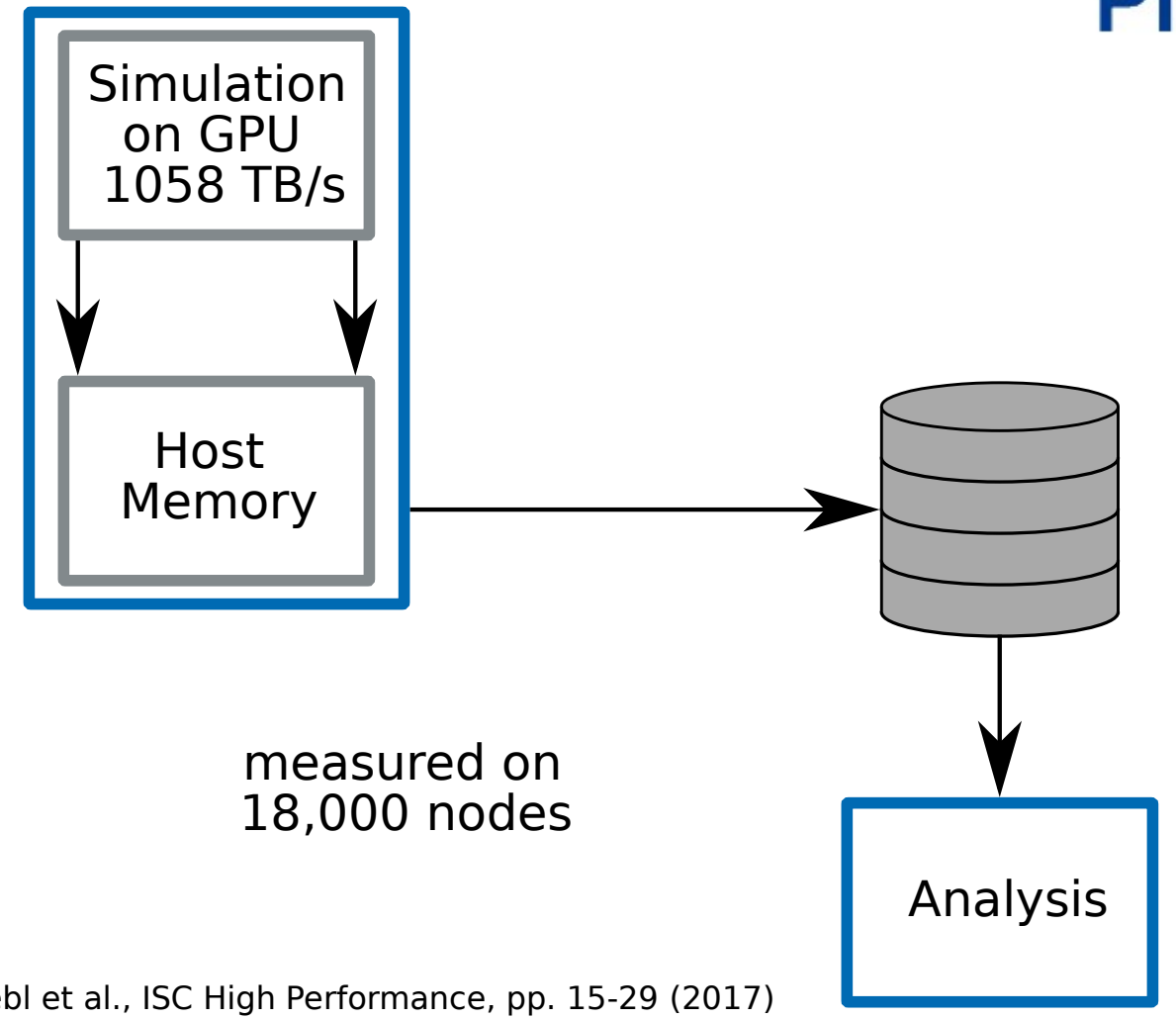
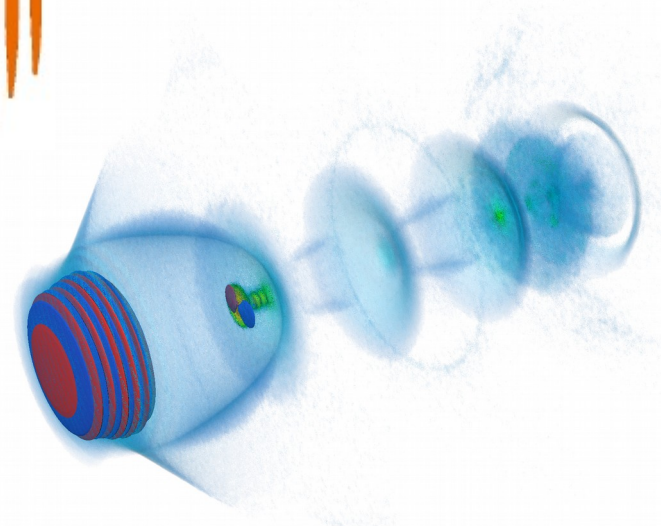


measured on
18,000 nodes



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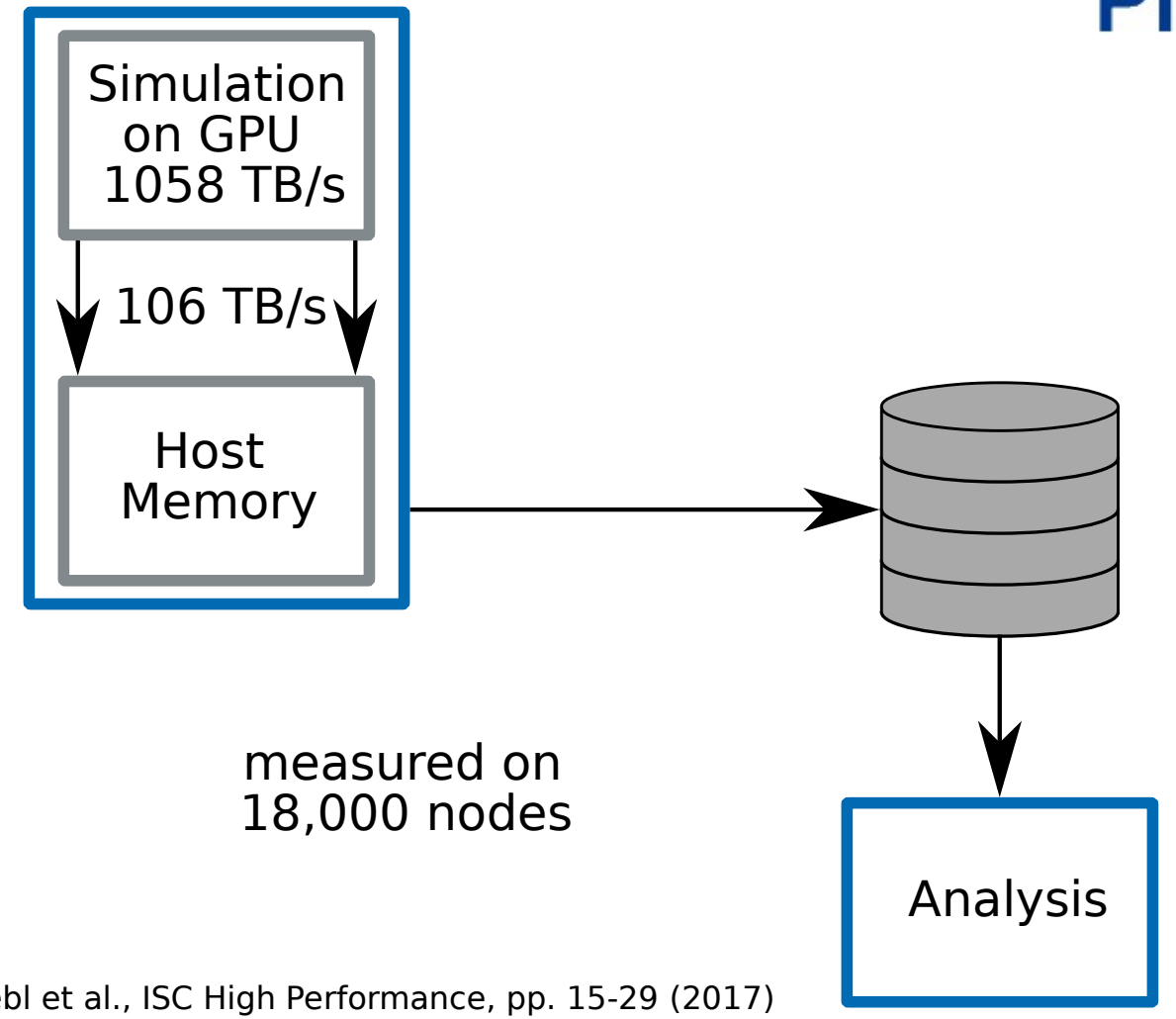

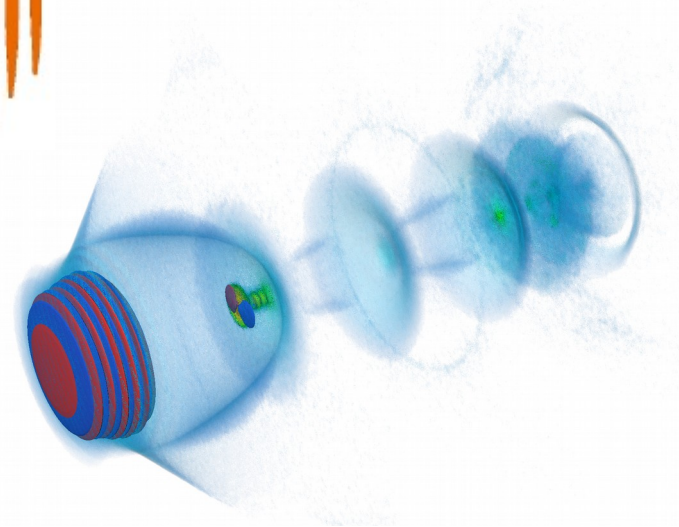

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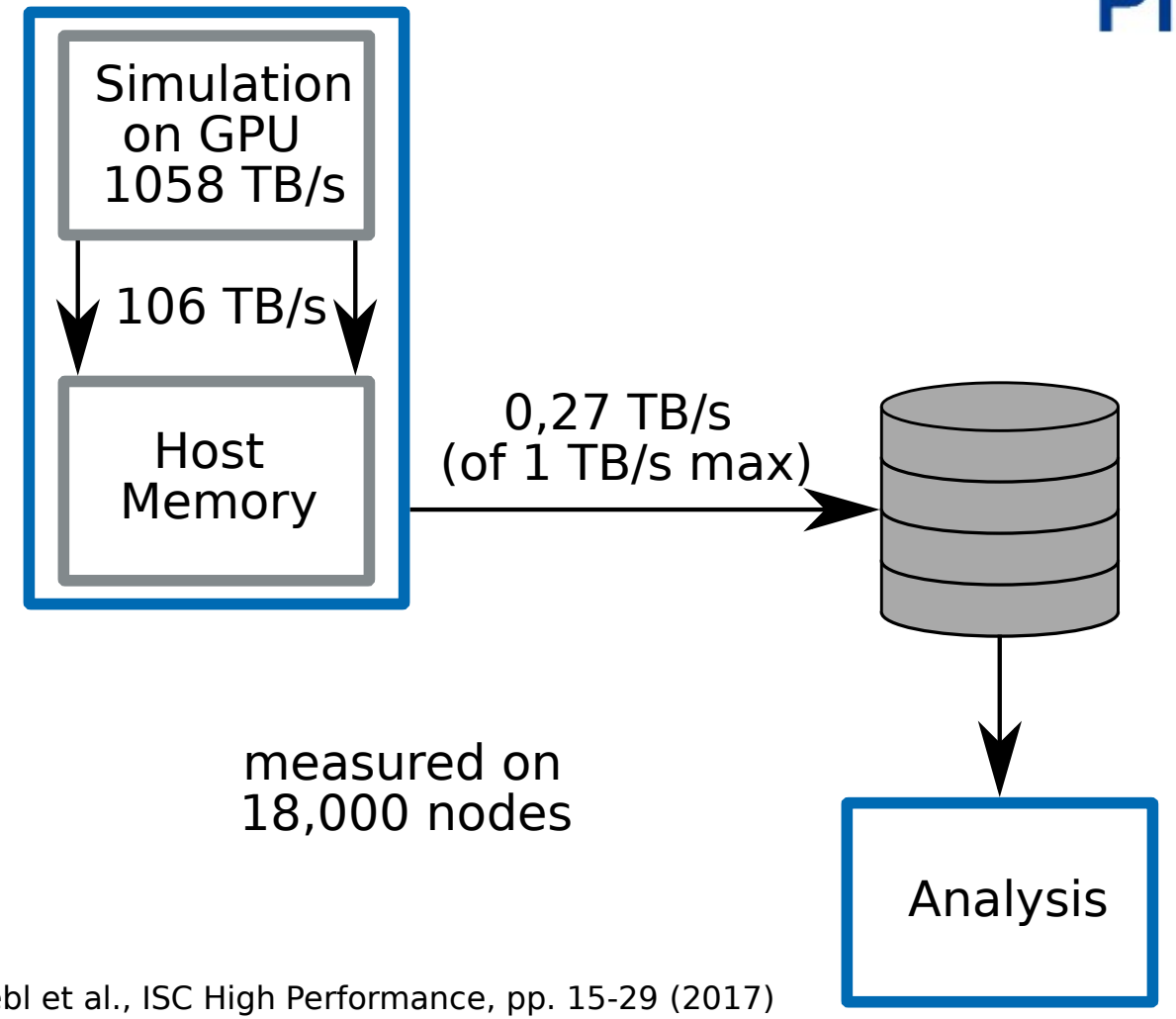

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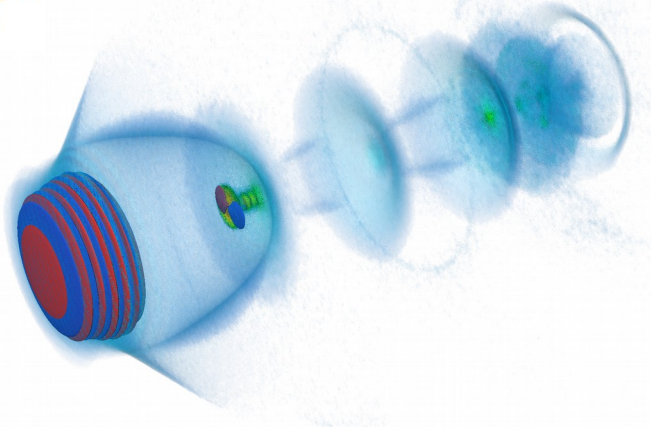

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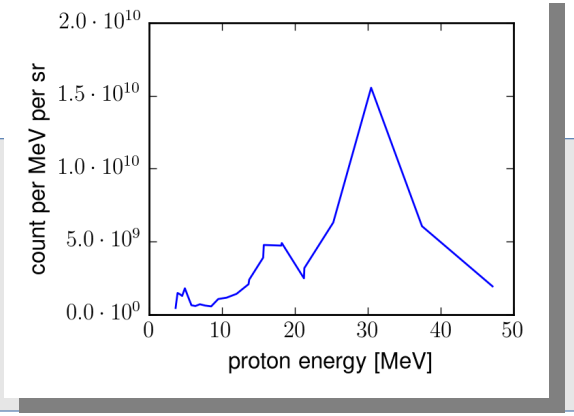
In Situ Data Analysis

Binning of a **spectrogram**
Creation of a **phase space image**



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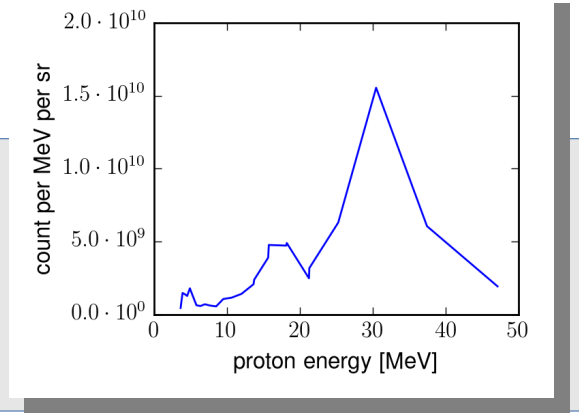
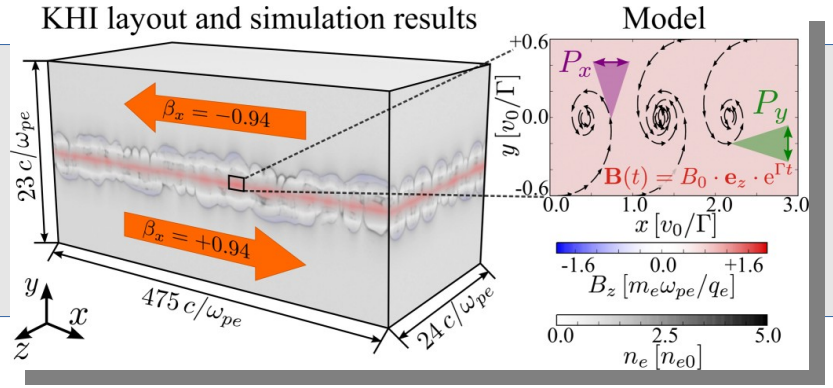


In situ **radiation diagnostics**



A. Huebl et al. (2014), DOI:10.1109/TPS.2014.2327392
R. Pausch et al. (2014, 2017, 2018), DOI:10.1103/PhysRevE.96.013316

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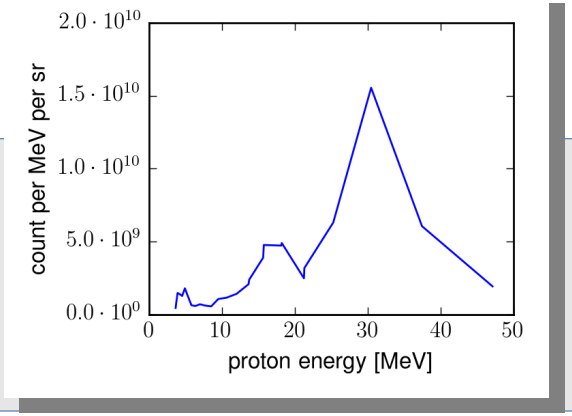

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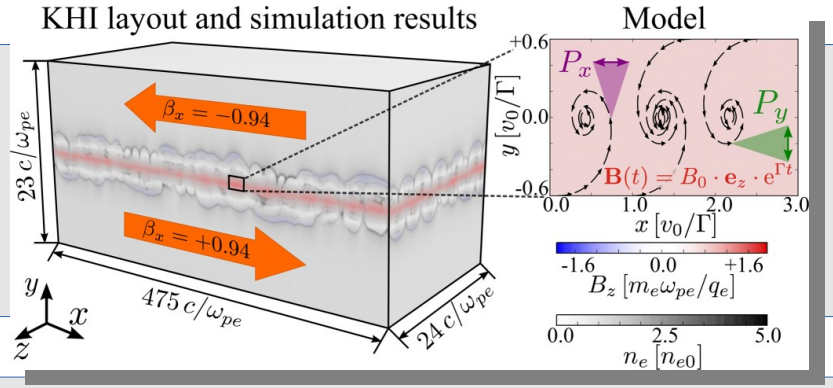

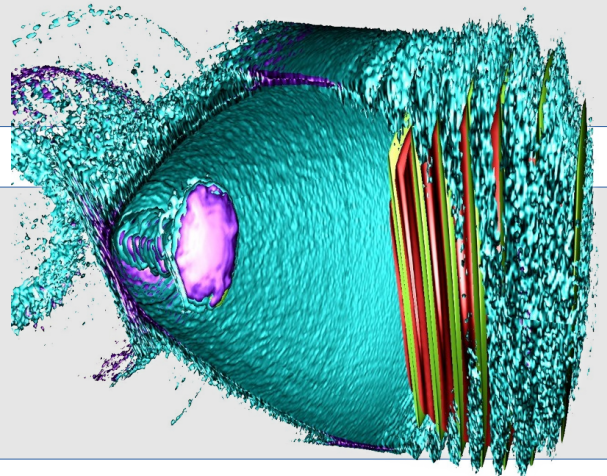

Ray-cast or photo-realistic ray-trace
Lossy data **compression**

A. Huebl et al. (2014), DOI:10.1109/TPS.2014.2327392
R. Pausch et al. (2014, 2017, 2018), DOI:10.1103/PhysRevE.96.013316
A. Matthes, A. Huebl et al., ISC'16 (2016), DOI:10.14529/jsfi160403
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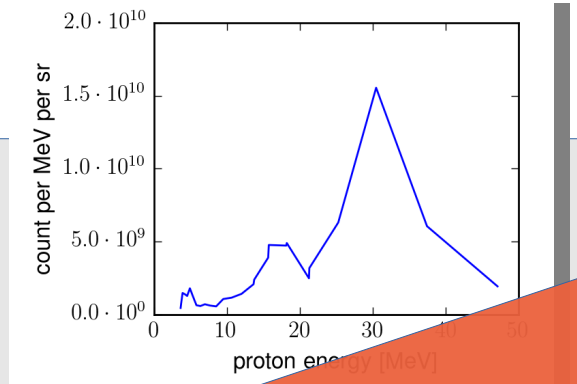
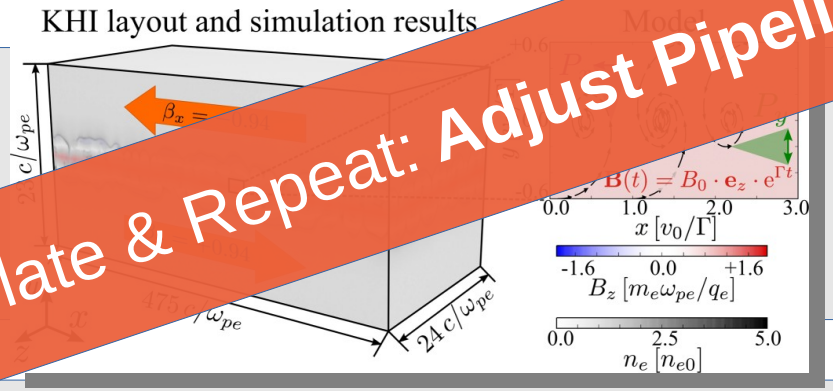
Binning of a **spectrogram**
Creation of a **phase space image**

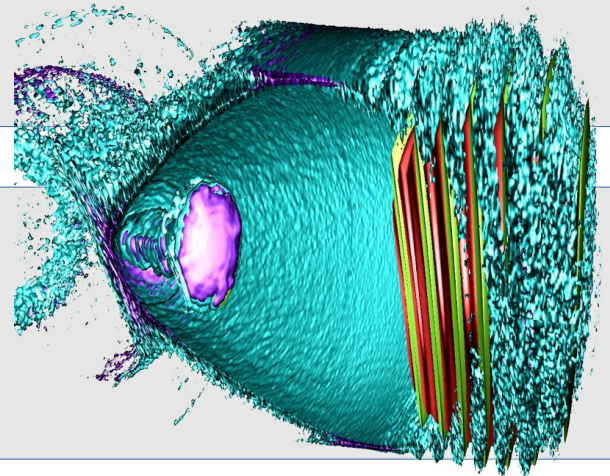


In situ **radiation diagnostics**



Observe, Correlate & Repeat: Adjust Pipeline

Ray-cast or photo-realistic ray-trace
Lossy data **compression**



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A. Huebl et al., ISC'17 (2017), DOI:10.1007/978-3-319-67630-2_2

Restriction of Analysis

- **I/O bandwidth** limits available data for analysis
- Analysis must be **integrated** into the simulation in-situ

- If you know **what to look** for: pre-configured, fixed analysis
- **Explorative** studies: require **feedback** to the simulation
  - **runtime-dependent** data analysis **kernels**
  - **optimize** kernels on runtime parameters
  - avoid explosion of **parameter space** at compile-time

[Game of Life Demo]

Current development

Cling-CUDA & Jupyter Extension Features

Feature	Status
CUDA Runtime support	✔ (see next slide)
Non-linear program flow	✔
Persistent memory	✔
Template specialization	✔
Includes and linking	✔
REPL Object Representation “`_repr_html_`”	✔
Reflection	✔
Redefinition of kernels	✘
Interaction with web elements	(✔)

Current Development

- Support additional CUDA features
  - `__constant__` device memory
  - global `__device__` variables
  - capture `printf` from kernels

- **Upstream**: features **merged**, follow-up patches submitted
- Implement **redefinition** support for **kernels**
- Support sophisticated C++ libraries in CUDA mode, e.g.
  - **xwidgets**: HTML buttons, sliders ...
  - **Alpaka**: our performance portability layer

Portable programming with Alpaka

CASUS
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- Alpaka is a C++14 header-only library, providing a GPU/CPU performance-portability layer

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alpaka

```
using Acc1 = alpaka::acc::AccCpuOmp2Blocks<Dim, Idx>;
using Acc2 = alpaka::acc::AccGpuCudaRt<Dim, Idx>;
// ...
auto func = [ ] ALPAKA_FN_ACC ( Acc const & acc) -> void {
                  printf("Hello World\n");
                };

// run Hello World parallel on CPU
alpaka::kernel::exec<Acc1>(queue, workDiv1, func);
// run Hello World parallel on GPU
alpaka::kernel::exec<Acc2>(queue, workDiv2, func);
```

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Getting started

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  - Linux
  - Nvidia Driver > 375.26
  - Singularity > 3.3, see https://sylabs.io/guides/3.5/user-guide/
  - Web browser (Firefox or Chrome recommended)

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- Nvidia Parallel For All blog post with details and example is work in progress

Source Code

- Cling:
  https://github.com/root-project/cling
- experimental Cling-CUDA features:
  https://github.com/SimeonEhrig/cling
- example notebook and container:
  https://github.com/ComputationalRadiationPhysics/Xeus-Cling-CUDA-Example/tree/master/GOL-function-presentation
- PIConGPU:
  https://github.com/ComputationalRadiationPhysics/picongpu
- Alpaka:
  https://github.com/ComputationalRadiationPhysics/alpaka
- Cling-CUDA diploma thesis (in German)
  https://doi.org/10.5281/zenodo.3713682

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QuantStack
Scientific Computing

CERN

Group: M. Bussmann

S. Corlay, J. Mabille et al., *Jupyter-Xeus*

A. Naumann, et al. *Cling (ROOT)*

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Basics

March 19, 2020

1 About

This notebook demonstrates features of Cling, Xeus-Cling and Jupyter Notebook.

2 Hello World

[1]:
```
#include <iostream>

std::cout << "Hello World" << std::endl;
```

```
Hello World
```

- No main() necessary
- each statement is in global space
- some statements are forbidden in global space, like function calls ...
- ... but Cling handles such situations and transforms these statements internally

3 Global and Local Variables

[2]:
```
// global variable
int g1 = 1;
```

[3]:
```
// local variable
{
    int l1 = 2;
}
```

[4]:
```
std::cout << l1 << std::endl;
```

```
input_line_11:2:15: error: use of undeclared identifier
'l1'
 std::cout << l1 << std::endl;
              ^


        Interpreter Error:
```

[5]:
```
std::cout << g1 << std::endl;
{
    // hide global variable
    int g1 = 3;
    std::cout << g1 << std::endl;
}
std::cout << g1 << std::endl;
```

```
1
3
1
```

4 Standard C++ Features

[6]:
```
int fd1(int k){
    return k + 2;
}
```

[7]:
```
std::cout << fd1(3) << std::endl;
```

```
5
```

[8]:
```
class Cd1 {
  int a;
  int b;

public:
    Cd1(int a, int b) : a(a), b(b) {}
    int sum(){
        return a + b;
    }
};
```

[9]:
```
Cd1 cd1(4, 7);
std::cout << cd1.sum() << std::endl;
```

```
11
```

5 Non-Linear Program Flow

[15]:
```
std::cout << non_lin_var << std::endl;
```

```
4
```

[13]:
```
++non_lin_var;
```

[11]:
```
int non_lin_var = 3;
```

6 Persistent Memory

[16]:
```
int k = 0;
```

[20]:
```
for (int end = k + 5; k < end; ++k){
    std::cout << k << std::endl;
}
```

```
7
8
9
10
11
```

[19]:
```
k -= 3;
```

7 Template Specialization

[21]:
```
#include <chrono>
constexpr int dim = 512;
```

[22]:
```
float * A = new float[dim * dim];
float * B = new float[dim * dim];
float * C = new float[dim * dim];
```

[23]:
```
for(int i = 0; i < dim; ++i){
    A[i] = static_cast<float>(i);
    B[i] = static_cast<float>(i);
}
```

[24]:
```
void var_matmul(float const * const A, float const * const B, float * const C,␣
 ↪const int dim)
{
    float sum = 0.f;
    for (int i = 0; i < dim; ++i) {
      for (int j = 0; j < dim; ++j) {
        for (int k = 0; k < dim; ++k) {
          sum += A[i * dim + k] * B[k * dim + j];
        }
        C[ i * dim + j] = sum;
        sum = 0.f;
      }
    }
}
```

[25]:
```
template<int dim>
void t_matmul(float const * const A, float const * const B, float * const C)
{
    float sum = 0.f;
    for (int i = 0; i < dim; ++i) {
      for (int j = 0; j < dim; ++j) {
        for (int k = 0; k < dim; ++k) {
          sum += A[i * dim + k] * B[k * dim + j];
        }
        C[ i * dim + j] = sum;
        sum = 0.f;
      }
    }
}
```

[26]:
```
var_matmul(A, B, C, dim);
t_matmul<dim>(A,B,C);
```

[27]:
```
{
    std::chrono::time_point<std::chrono::high_resolution_clock> v_start, v_end,␣
 ↪t_start, t_end;

    v_start = std::chrono::high_resolution_clock::now();
    var_matmul(A, B, C, dim);
    v_end = std::chrono::high_resolution_clock::now();

    t_start = std::chrono::high_resolution_clock::now();
```

```
    t_matmul<dim>(A, B, C);
    t_end = std::chrono::high_resolution_clock::now();

    std::chrono::duration<double> v_diff = v_end - v_start;
    std::chrono::duration<double> t_diff = t_end - t_start;

    std::cout << "var_matmul: " << v_diff.count() << "s" << std::endl
              << "t_matmul: " << t_diff.count() << "s" << std::endl;
}
```

```
var_matmul: 0.540087s
t_matmul: 0.530416s
```

8 Including and Linking

8.1 Preparation: create a shared library

[28]:
```
%%file foo.hpp
#pragma once

namespace foo {
    int bar();
}
```

```
Overwriting foo.hpp
```

[29]:
```
%%file foo.cpp
#include "foo.hpp"

int foo::bar() { return 42; }
```

```
Overwriting foo.cpp
```

[30]:
```
!gcc -shared foo.cpp -o foo.so
```

8.2 Call Functionality of the Library

[31]:
```
foo::bar()
```

```
input_line_36:2:2: error: use of undeclared identifier
'foo'
 foo::bar()
 ^
```

```
Interpreter Error:
```

[32]:
```
#include "foo.hpp"
```

[33]:
```
foo::bar()
```

```
IncrementalExecutor::executeFunction: symbol '_ZN3foo3barEv' unresolved while
linking [cling interface function]!
You are probably missing the definition of foo::bar()
Maybe you need to load the corresponding shared library?
```

```
Interpreter Error:
```

[34]:
```
#pragma cling(load "foo.so")
```

[35]:
```
foo::bar()
```

[35]:
```
42
```

9 REPL Object Representation

[36]:
```
"Hello World"
```

[36]:
```
"Hello World"
```

[37]:
```
int i1 = 3;
```

[38]:
```
i1
```

[38]:
```
3
```

[39]:
```
int fi1(){
    return 42;
}
```

[40]:
```
fi1()
```

[40]:
```
42
```

10 Reflection

- values of variables
- type of a variable (cling kernel only)
- memory address
- enum completion (cling kernel only)
- interpreter environment

[41]:
```
struct S {
    int a = 3;
    float b = 6,f;
} s;
```

[42]:
```
s
```

[42]:
```
@0x7fa5267b9054
```

[43]:
```
s.a
```

[43]:
```
3
```

[44]:
```
#include "cling/Interpreter/Interpreter.h"
```

[45]:
```
gCling->getDefaultOptLevel()
```

[45]:
```
0
```

[46]:
```
gCling->setDefaultOptLevel(3)
```

11 Redefinition

[47]:
```
#include "cling/Interpreter/Interpreter.h"
gCling->allowRedefinition();
gCling->isRedefinitionAllowed();
```

[48]:
```
int func(){
    return 43;
}
```

[49]:
```
func()
```

[49]:
```
43
```

[50]:
```
int func(){
    return 42;
```

```
}
```

[51]:
```
func()
```

[51]:
```
42
```

[52]:
```
class class1 {
    int a = 3;
    int b = 4;
public:
    int func() {
        return a + b;
    }
};
```

[53]:
```
{
    class1 c;
    std::cout << c.func() << std::endl;
}
```

```
7
```

[54]:
```
class class1 {
    int a = 3;
    int b = 40;
public:
    int func() {
        return a + b;
    }
};
```

[55]:
```
{
    class1 c;
    std::cout << c.func() << std::endl;
}
```

```
43
```

12 I/O through Web Elements

[56]:
```
#include <string>
#include <fstream>

#include "xtl/xbase64.hpp"
#include "xeus/xjson.hpp"
```

[57]:
```
void display_image(const std::string filename){
    std::ifstream fin(filename, std::ios::binary);
    std::stringstream buffer;
    buffer << fin.rdbuf();
    // memory objects for output in the web browser

    xeus::xjson mine;

    xeus::get_interpreter().clear_output(true);

    mine["image/png"] = xtl::base64encode(buffer.str());
    xeus::get_interpreter().display_data(
        std::move(mine),
        xeus::xjson::object(),
        xeus::xjson::object());
}
```

[58]:
```
display_image("pictures/conclusion_basics.png");
```

Conclusion

Changed Behavior

- Simplified syntax
- Non-linear flow
- Persistent memory
- Template parameters at runtime
- linking at runtime

New Features

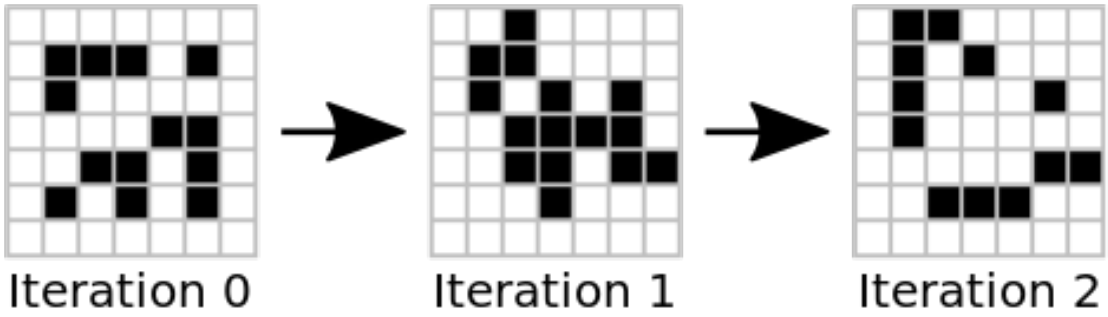
- REPL Object Representation
- Reflection
- Redefinition
- I/O with web elements
- Features of Jupyter Notebook

GameOfLife

March 20, 2020

1 Game of Life on GPU - Interactive & Extensible

- The example shows an interactive workflow of simulation and analysis.
- The simulation runs Conway's Game of Life on a GPU.



2 Include and Link

[1]:
```
// set the include path of PNGwriter
//   https://github.com/pngwriter/pngwriter/tree/dev
// (like -Ipngwriter/include for a compiler)
#pragma cling(add_include_path "pngwriter/include")

#include <fstream>
#include <vector>
#include <sstream>
#include <chrono>
#include <thread>

// include PNGwriter
#define NO_FREETYPE
#include <pngwriter.h>

// helper functions for displaying images
#include "xtl/xbase64.hpp"
#include "xeus/xjson.hpp"
```

```
// self-defined helper functions
#include "color_maps.hpp"
#include "input_reader.hpp"
#include "png_generator.hpp"
#include "helper.hpp"

// link PNGwriter (like -lPNGwriter for a compiler)
#pragma cling(load "pngwriter/lib/libPNGwriter.so")
```

3 Game of Life Setup

- setup world size
- allocate memory on CPU and GPU
- load initial world
- copy initial world to the GPU
- generate image of the initial world

[2]:
```
// size of the world
const unsigned int dim = 10u;
// two extra columns and rows for ghostcells
const unsigned int world_size = dim + 2u;
unsigned int iterations = 5;
unsigned int current_png = 0;

// pointers for host and device memory
int * sim_world;
int * d_sim_world;
int * d_new_sim_world;
int * d_swap;
// allocate memory on CPU and GPU
sim_world = new int[ world_size * world_size ];
cuCheck(cudaMalloc( (void **) &d_sim_world, sizeof(int)*world_size*world_size));
cuCheck(cudaMalloc( (void **) &d_new_sim_world,␣
 ↪sizeof(int)*world_size*world_size));

// read initial world from a file
if (int error = read_input("input.txt", sim_world, dim, dim, true))
    std::cout << "read input world failed - error code: " << error << std::endl;

// copy initial world to GPU
cuCheck(cudaMemcpy(d_sim_world, sim_world, sizeof(int)*world_size*world_size,␣
 ↪cudaMemcpyHostToDevice));

// allocate memory for the simulation images
std::vector< std::vector< unsigned char > > sim_pngs;
```

```
// create an image of the initial world
BlackWhiteMap<int> bw_map;
sim_pngs.push_back(generate_png<int>(sim_world, world_size, world_size,␣
 ↪&bw_map, true, 20));
```

4 CUDA Kernels

[3]:
```
// periodic boundary conditions: copy the first/last row/column
__global__ void update_boundaries(int dim, int *world) {
  int col = blockIdx.x * blockDim.x + threadIdx.x;
  int row = blockIdx.y * blockDim.y + threadIdx.y;

  // ignore the first two threads: only needed to copy ghost cells for columns
  if(col > 1) {
    if(row == 0) {
      // Copy first real row to bottom ghost row
      world[col-1 + (dim+2)*(dim+1)] = world[(dim+2)     + col-1];
    }else{
      // Copy last real row to top ghost row
      world[col-1]                   = world[(dim+2)*dim + col-1];
    }
  }
  __syncthreads();

  if(row == 0) {
    // Copy first real column to right most ghost column
    world[col*(dim+2)+dim+1] = world[col*(dim+2) + 1];
  } else {
    // Copy last real column to left most ghost column
    world[col*(dim+2)      ] = world[col*(dim+2) + dim];
  }

}
```

[4]:
```
// main kernel that calculates an iteration of the game of life
__global__ void GOL_GPU(int dim, int *world, int *newWorld) {
   int row = blockIdx.y * blockDim.y + threadIdx.y + 1;
   int col = blockIdx.x * blockDim.x + threadIdx.x + 1;
   int id = row*(dim+2) + col;

   int numNeighbors;
   int cell = world[id];

   numNeighbors =   world[id+(dim+2)]   // lower
      + world[id-(dim+2)]               // upper
```

```
      + world[id+1]                     // right
      + world[id-1]                     // left

      + world[id+(dim+3)]   // diagonal lower right
      + world[id-(dim+3)]   // diagonal upper left
      + world[id-(dim+1)]   // diagonal upper right
      + world[id+(dim+1)];  // diagonal lower left

   if (cell == 1 && numNeighbors < 2)
      newWorld[id] = 0;

    // 2) Any living cell with two or three living neighbors lives
    else if (cell == 1 && (numNeighbors == 2 || numNeighbors == 3))
      newWorld[id] = 1;

    // 3) Any living cell with more than three living neighbors dies
    else if (cell == 1 && numNeighbors > 3)
      newWorld[id] = 0;

    // 4) Any dead cell with exactly three living neighbors becomes alive
    else if (cell == 0 && numNeighbors == 3)
      newWorld[id] = 1;

    else
      newWorld[id] = cell;
}
```

5 Interactive Simulation: Main Loop

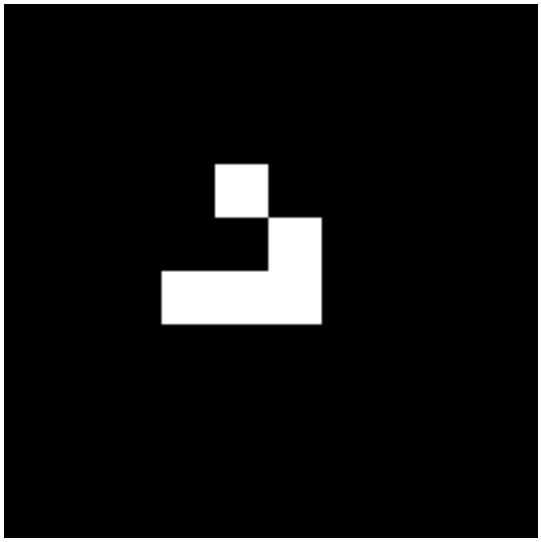
- calculate new iterations
- swap new world with the old one
- generate an image of the current iteration

[8]:
```
// main loop
for(unsigned int i = 0; i < iterations; ++i) {

    update_boundaries<<<1, dim3(dim+2, 2, 1)>>>(dim, d_sim_world);
    GOL_GPU<<<1, dim3(dim, dim, 1)>>>(dim, d_sim_world, d_new_sim_world);
    cuCheck(cudaDeviceSynchronize());

    d_swap = d_new_sim_world;
    d_new_sim_world = d_sim_world;
    d_sim_world = d_swap;
```

```
    cuCheck(cudaMemcpy(sim_world, d_sim_world,␣
 ↪sizeof(int)*world_size*world_size, cudaMemcpyDeviceToHost));
    sim_pngs.push_back(generate_png<int>(sim_world, world_size, world_size,␣
 ↪&bw_map, true, 20));
}
```

6 Display Simulation Images

[9]:
```
for(; current_png < sim_pngs.size(); ++current_png) {
    display_image(sim_pngs[current_png], true);
    std::cout << "iteration = " << current_png << std::endl;
    std::this_thread::sleep_for(std::chrono::milliseconds(800));
}
```



```
iteration = 8
```

6.1 Nonlinear Program Flow

[7]:
```
iterations = 3;
```

7 In-Situ Data Analysis

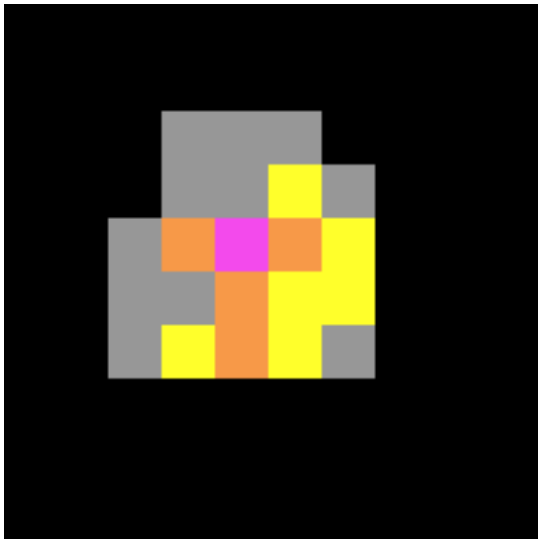
- heatmap of the living neighbors for each cell
- kernel uses the simulation result as its input and writes output to an extra buffer

[10]:
```
// counts the living neighbors of a cell
__global__ void get_num_neighbors(int dim, int *world, int *newWorld) {
   int row = blockIdx.y * blockDim.y + threadIdx.y + 1;
   int col = blockIdx.x * blockDim.x + threadIdx.x + 1;
   int id = row*(dim+2) + col;

   newWorld[id] =   world[id+(dim+2)]   // lower
      + world[id-(dim+2)]               // upper
      + world[id+1]                     // right
      + world[id-1]                     // left

      + world[id+(dim+3)]   // diagonal lower right
      + world[id-(dim+3)]   // diagonal upper left
      + world[id-(dim+1)]   // diagonal upper right
      + world[id+(dim+1)];  // diagonal lower left
}
```

- allocate memory for analysis on CPU and GPU
- run the analysis
- generate an image from the analysis result

[11]:
```
// allocate extra memory on the GPU to output the analysis
int * d_ana_world;
cuCheck(cudaMalloc( (void **) &d_ana_world, sizeof(int)*world_size*world_size));
// allocate memory on CPU for the images
std::vector< std::vector< unsigned char > > ana_pngs;
int * ana_world = new int[world_size*world_size];

// run the analysis
// use the simulation data as input and write the result into extra memory
get_num_neighbors<<<1,dim3(dim, dim, 1)>>>(dim, d_sim_world, d_ana_world);

// copy analysis data to the CPU
cuCheck(cudaMemcpy(ana_world, d_ana_world, sizeof(int)*world_size*world_size,␣
 ↪cudaMemcpyDeviceToHost));
// generate a heat map image
ana_pngs.push_back(generate_png<int>(ana_world, world_size, world_size,␣
 ↪&ch_map, true, 20));
```

[12]:
```
display_image(ana_pngs.back(), true);
```

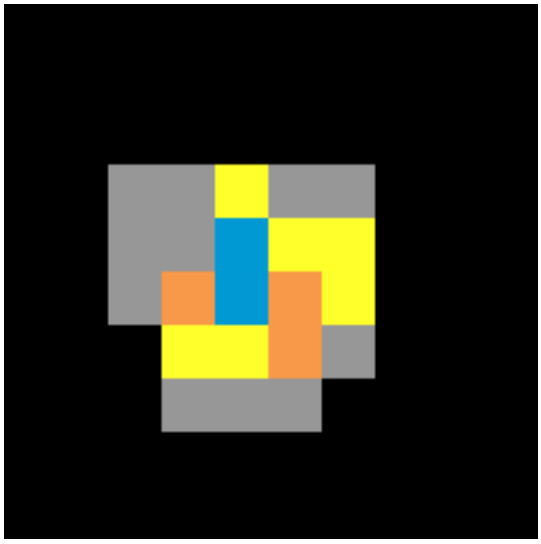


8 Run a single Simulation step with Analysis

[13]:
```
// one iteration of the simulation
update_boundaries<<<1, dim3(dim+2, 2, 1)>>>(dim, d_sim_world);
GOL_GPU<<<1, dim3(dim, dim, 1)>>>(dim, d_sim_world, d_new_sim_world);
cuCheck(cudaDeviceSynchronize());

// swap memory
d_swap = d_new_sim_world;
d_new_sim_world = d_sim_world;
d_sim_world = d_swap;
```

[14]:
```
// run analysis
get_num_neighbors<<<1,dim3(dim, dim, 1)>>>(dim, d_sim_world, d_ana_world);
cuCheck(cudaMemcpy(ana_world, d_ana_world, sizeof(int)*world_size*world_size,␣
 ↪cudaMemcpyDeviceToHost));
ana_pngs.push_back(generate_png<int>(ana_world, world_size, world_size,␣
 ↪&ch_map, true, 20));
```

[15]:
```
display_image(ana_pngs.back(), true);
```



9 Extras

9.1 Interactive Input

- Jupyter Notebook offers "magic" commands that provide language-independent functions
- magic commands starts with `%%`
- `%%file [name]` writes the contents of a cell to a file
  - the file is stored in the same folder as the notebook and can be loaded via C/C++ functions
- depends on the language kernel (xeus features)

Define the initial world for the Game of Life simulation. `X` are living cells and `0` are dead.

[ ]:
```
%%file input.txt
0 0 0 0 0 0 0 0 0 0
0 0 X 0 0 0 0 0 0 0
0 0 0 X 0 0 0 0 0 0
0 X X X 0 0 0 0 0 0
0 0 0 0 0 0 0 0 0 0
0 0 0 0 0 0 0 0 0 0
0 0 0 0 0 0 0 0 0 0
0 0 0 0 0 0 0 0 0 0
0 0 0 0 0 0 0 0 0 0
0 0 0 0 0 0 0 0 0 0
```

9.2 Reset the simulation without restarting the kernel

[ ]:
```
// load a new inital world into the host memory
read_input("input.txt", sim_world, dim, dim, true);
// copy the world to the device
cuCheck(cudaMemcpy(d_sim_world, sim_world, sizeof(int)*world_size*world_size,␣
 ↪cudaMemcpyHostToDevice));
// reset png print counter
current_png = 0;
// delete old images
sim_pngs.clear();
// create an image of the initial world
sim_pngs.push_back(generate_png<int>(sim_world, world_size, world_size,␣
 ↪&bw_map, true, 20));
```