OAK RIDGE National Laboratory

Scaling Full-system Simulation of ARM SVE Processors Using Compilers and Runtime Tool APIs

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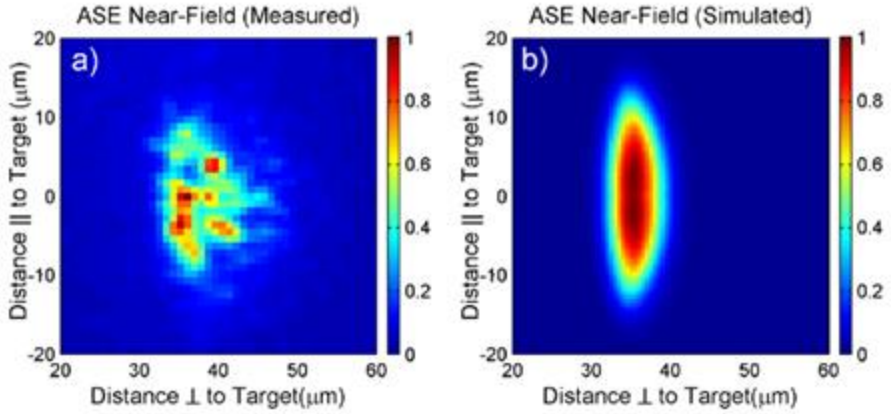
U.S. DEPARTMENT OF ENERGY

Improving Co-design of Software and Hardware

- Software
  - The DoE uses mini-apps to represent workloads of interest, many using OpenMP or CUDA
- Hardware
  - Can we use simulation to model future hardware and architectures at scale?
- We also want to investigate how OpenMP mini-apps might be vectorized for future SVE or vector-based hardware
  - XRayTrace, XGC, EPCC, etc.



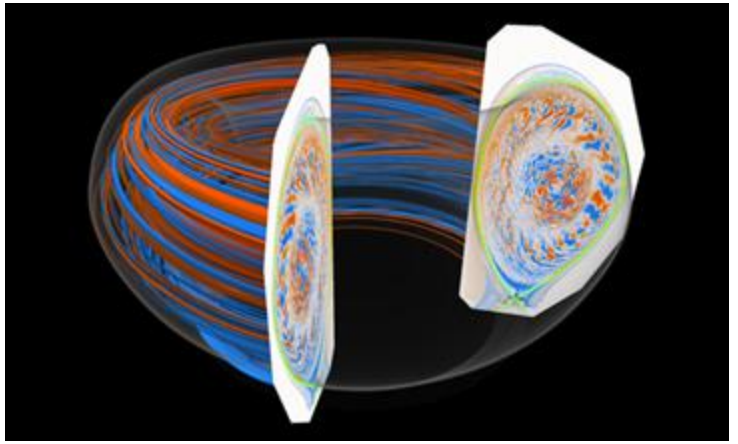


Photo sources: C.-S. Chang, Present and Future Computing Requirements for Tokamak Edge Physics https://www.nersc.gov/assets/Uploads/CSChang.pdf
M. Berrill, XRayTrace Miniapp presentation, 2017

Current Problems for Co-Design

- It is impractical to simulate an entire program; we must pick *regions of interest* (ROI)
- However, it is much more challenging to programmatically pick regions of interest.
  - Many current techniques are intrusive (i.e., manual pragma insertion) and are not conducive to reproducibility
  - Examples:
    - Gem5 manual ROI and checkpointing, ARMIE ROI for memory tracing

```
[bzf@wombat-login2 gem5-tools]$ cat checkpoint.c
#include <gem5ops.h>

int main(int argc, char** argv)
{
        m5_checkpoint(0,0);
        return 0;
}
[bzf@wombat-login2 gem5-tools]$ armie -msve-vector-bits=2048 --iclient libinscount_emulated.so ./check
point
Client inscount is running
261312 instructions executed of which 0 were emulated instructions

Guest process terminated by signal: 15687 Illegal instruction ./checkpoint
[bzf@wombat-login2 gem5-tools]$
```

How do we make codesign easier and more scalable?

- Use tooling to identify and simulate regions of interest
  - OpenMP Tools (OMPT) interface to instrument applications at runtime
  - Handle incompatibilities between tools like gem5 and ARMIE
    - ARMIE is unhappy when it runs into gem5 magic instructions!
- Provide a consistent runtime between simulation environments
  - Use containers to bring user defined software stacks across tools
  - Specifically, use Charliecloud to deploy tool-friendly mini-apps for ARMIE and gem5
- Combine OMPT techniques with CharlieCloud to provide isolation and easy of deployment
  - Different OMP tools can be built as a separate libraries and then run with whatever OMP 5.0 runtime is part of a disk image or container

OMPT for runtime simulator hooks

- OMPT is a new tool interface for OpenMP 5.0+
- Allows tool developers to add analysis and introspection to the OpenMP runtime
  - Mini-app annotations can be added in a non-intrusive way
  - No need to manually instrument code with gem5 ops or ARMIE ROI pragmas; OMPT callbacks can be used to add annotations

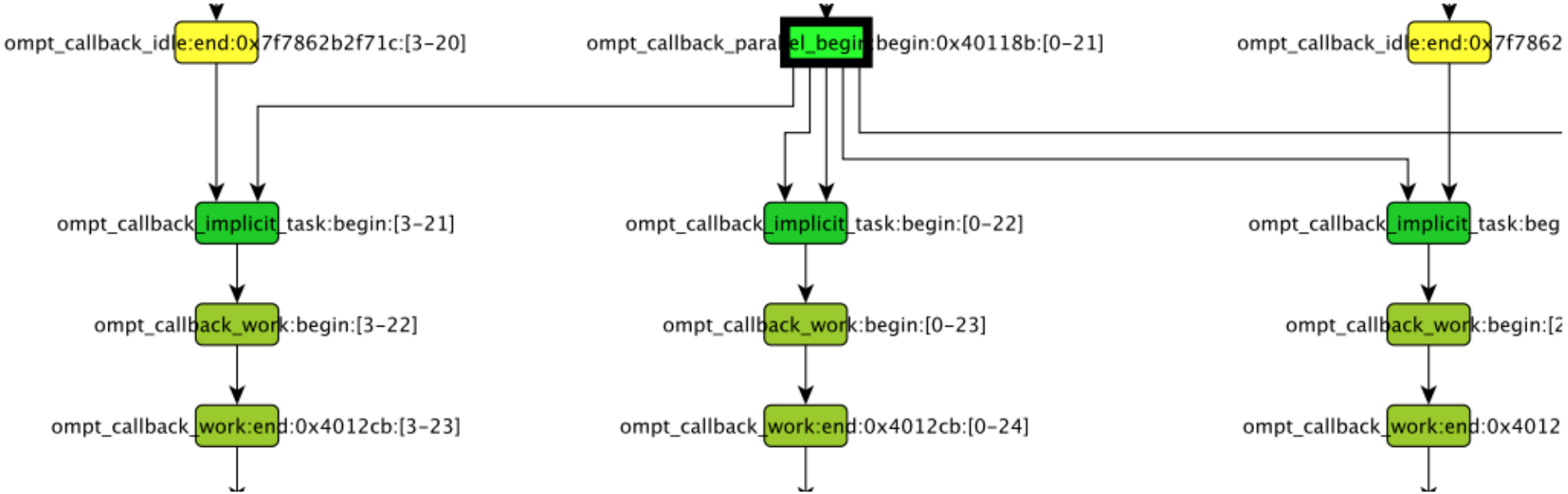
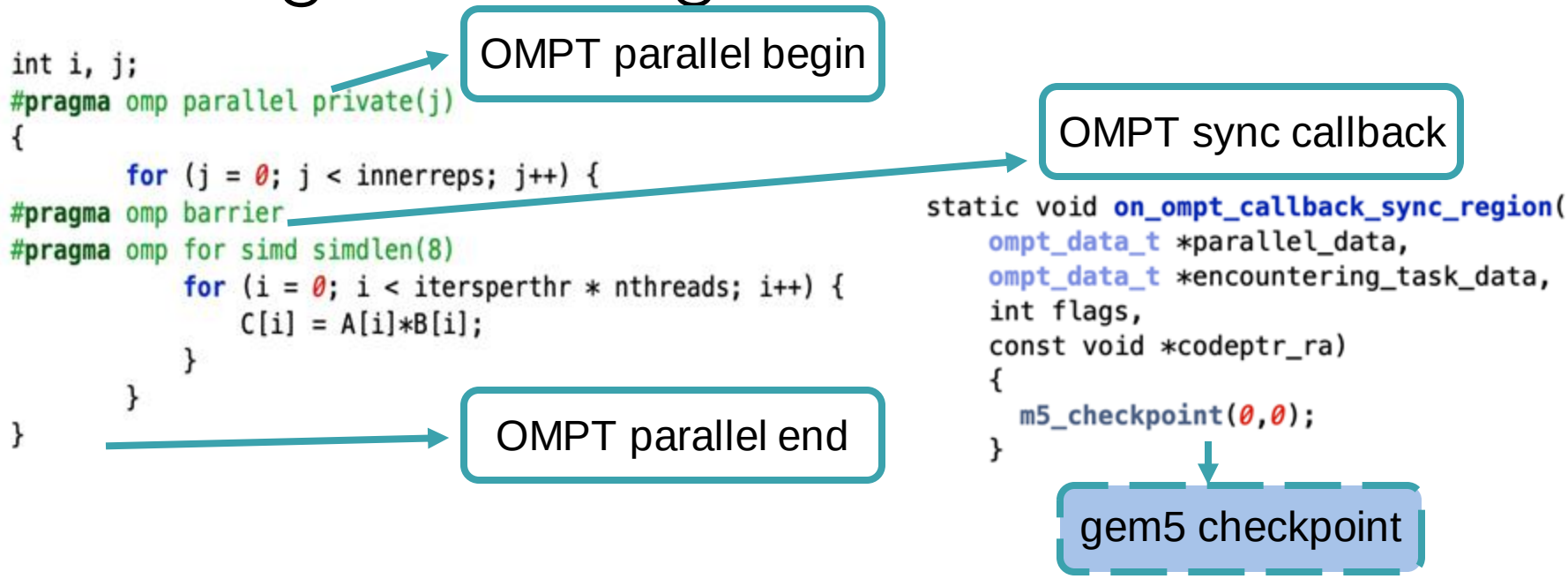


Image from Yonghong Yan, Philip Conrad, Yudong Sun, "Visualizing OpenMP Execution using OMPT". SC 2018

Extending OMPT for gem5 Simulations

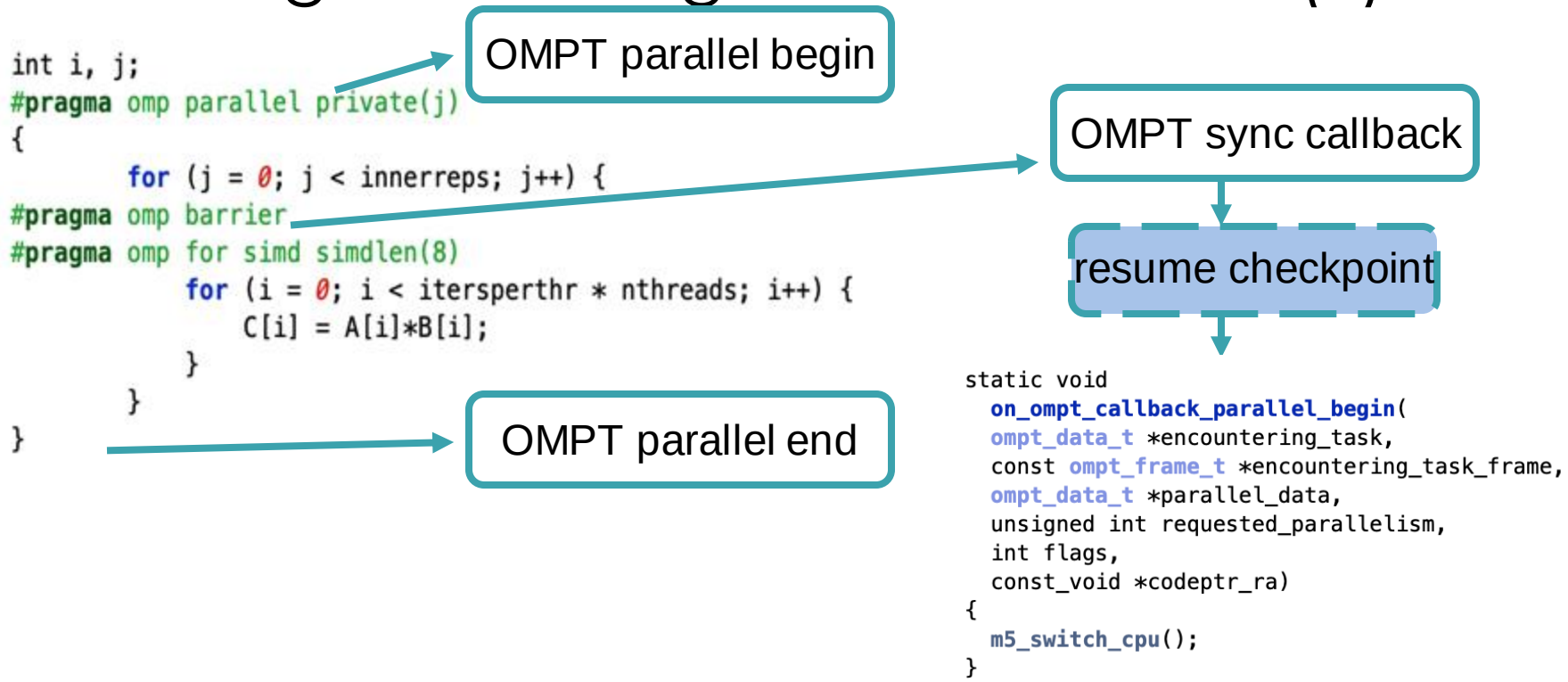



```
int i, j;
#pragma omp parallel private(j)
{
        for (j = 0; j < innerreps; j++) {
#pragma omp barrier
#pragma omp for simd simdlen(8)
            for (i = 0; i < itersperthr * nthreads; i++) {
                C[i] = A[i]*B[i];
            }
        }
}
```

```
static void on_ompt_callback_sync_region(
    ompt_data_t *parallel_data,
    ompt_data_t *encountering_task_data,
    int flags,
    const void *codeptr_ra)
{
  m5_checkpoint(0,0);
}
```

- Initial work has used the OpenMP Tools API to drop gem5 checkpoints with simulators like gem5
- OMPT callbacks can be currently used to track *omp_parallel, omp_barrier, omp_single*

Extending OMPT for gem5 Simulations (2)



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Creating a Consistent environment For Simulations

- Ensuring consistent behavior of mini-apps between environments
- Simulators often have their own quirks that need to be managed
- Leverage containers to ensure consistent runtime environment
- Applications to run in simulation may be bundled as containers
  - Easier to distribute
  - Same binary between simulators
  - Reproducible

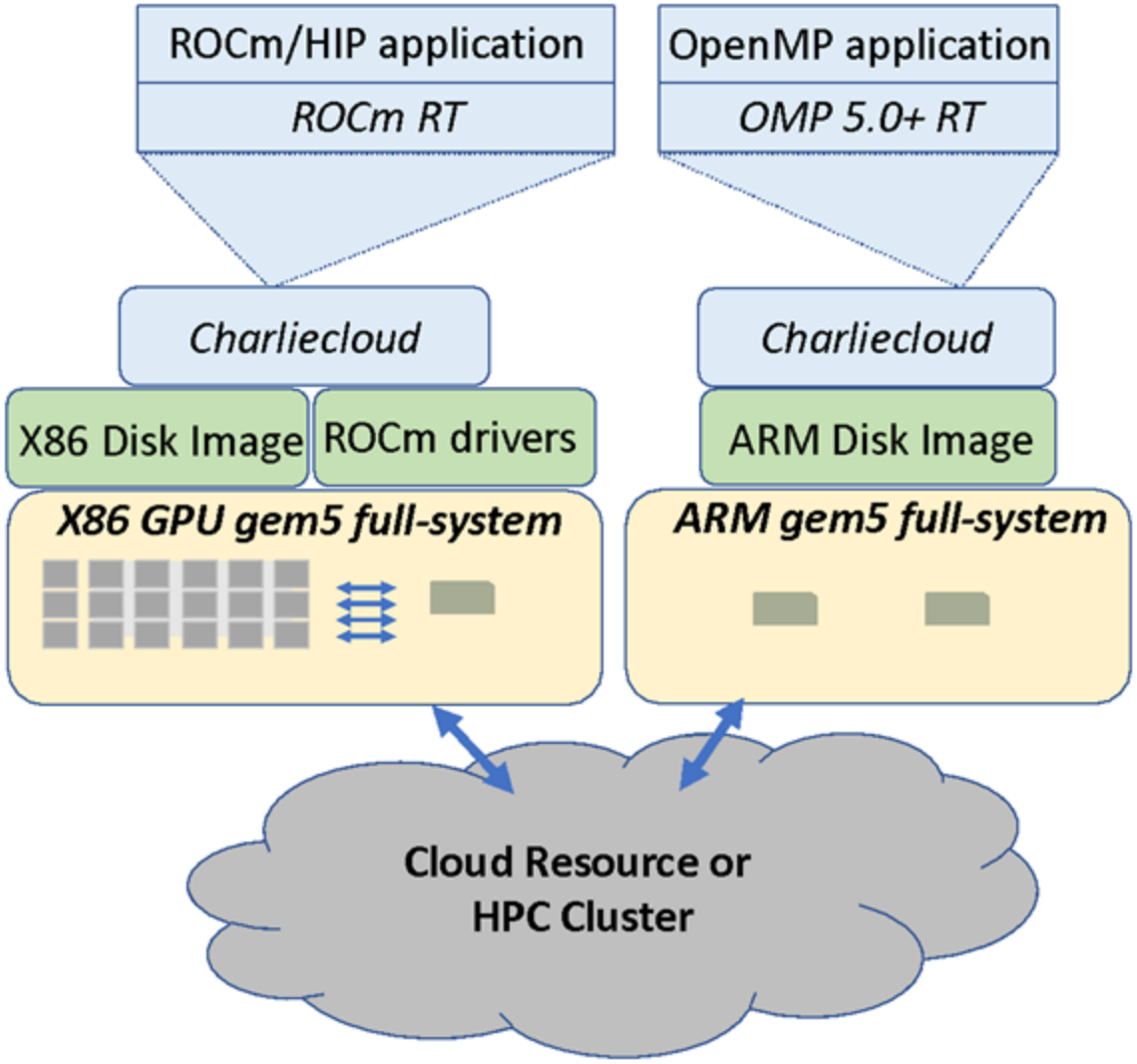
Why Charliecloud?

- While most container environments have heavy requirements and root privileges, Charliecloud does not
  - Simple to include in gem5 full system simulation or run in HPC centers
    - Just need its ch-run binary!
  - Container image flattened into tarball
    - Extract into new directory and container environment is a ch-run away
- Host environment tools can be leveraged with bind mounts
  - ARMIE home dir can be bind mounted into container directory
    - ARMIE tools are then available inside isolated, user defined environment
  - gem5 can bind gem5 OMPT enabled tool directory into simulations

```
[bzf@wombat-login2 slides]$ tar xf simdbench.tar.gz -C simdbench
[bzf@wombat-login2 slides]$ ch-run --bind $ARMIE_PATH simdbench -- /mnt/0/bin64/armie -msve-vector-bit
s=2048 --iclient libinscount_emulated.so /app/simdbench
Client inscount is running
SVE: 0x0000000000401688 0x043f57df
```

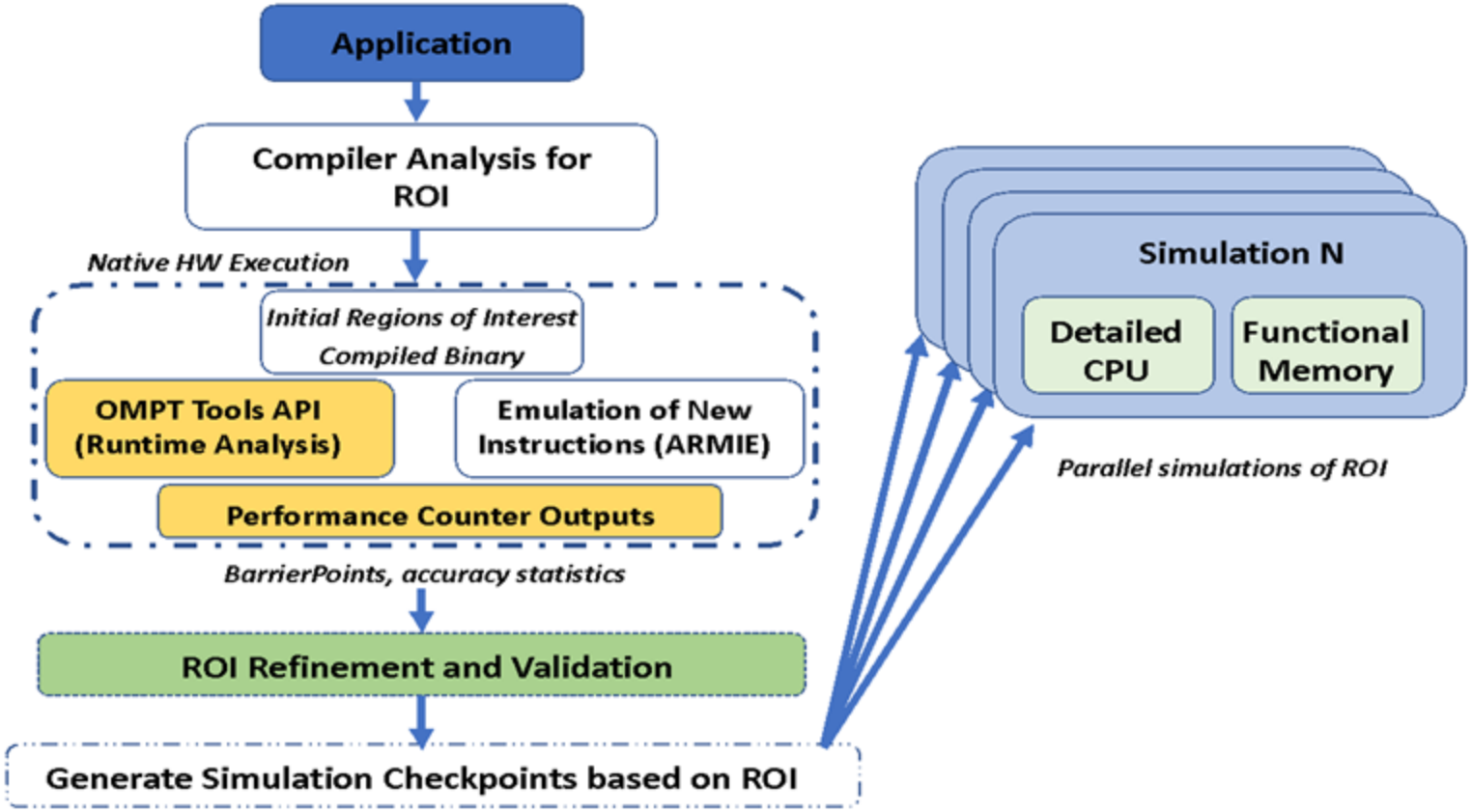
Deployment of Design Space Exploration at Scale

- Allow users to create their own lightweight simulation containers inside FS simulations
- Mirrors current use-cases for systems like Summit (Docker, Singularity) and reduces deployment overheads



Future Work

- Integrate OMPT techniques with BarrierPoint work
- Develop additional OMPT based tools for improving simulation execution and instrumentation



Based on work by Miguel Tairum Cruz, Sascha Bischoff, Roxana Rusitoru, "Shifting the Barrier: Extending the Boundaries of the BarrierPoint Methodology". ISPASS 2018

Acknowledgments

- This work was funded by an Oak Ridge National Laboratory Directed Research & Development (LDRD) project
- This research used resources of the Oak Ridge Leadership Computing Facility, which is a DOE Office of Science User Facility supported under Contract DE-AC05-00OR22725.

Backup

What is a Barrier Point?

```
#pragma omp parallel for
for (j = 0; j < innerreps; j++)
{
  #pragma omp barrier
  for (i = 0; i < itersperthr * nthreads; i++)
  {
    C[i] = A[i]*B[i];
  }
}
```

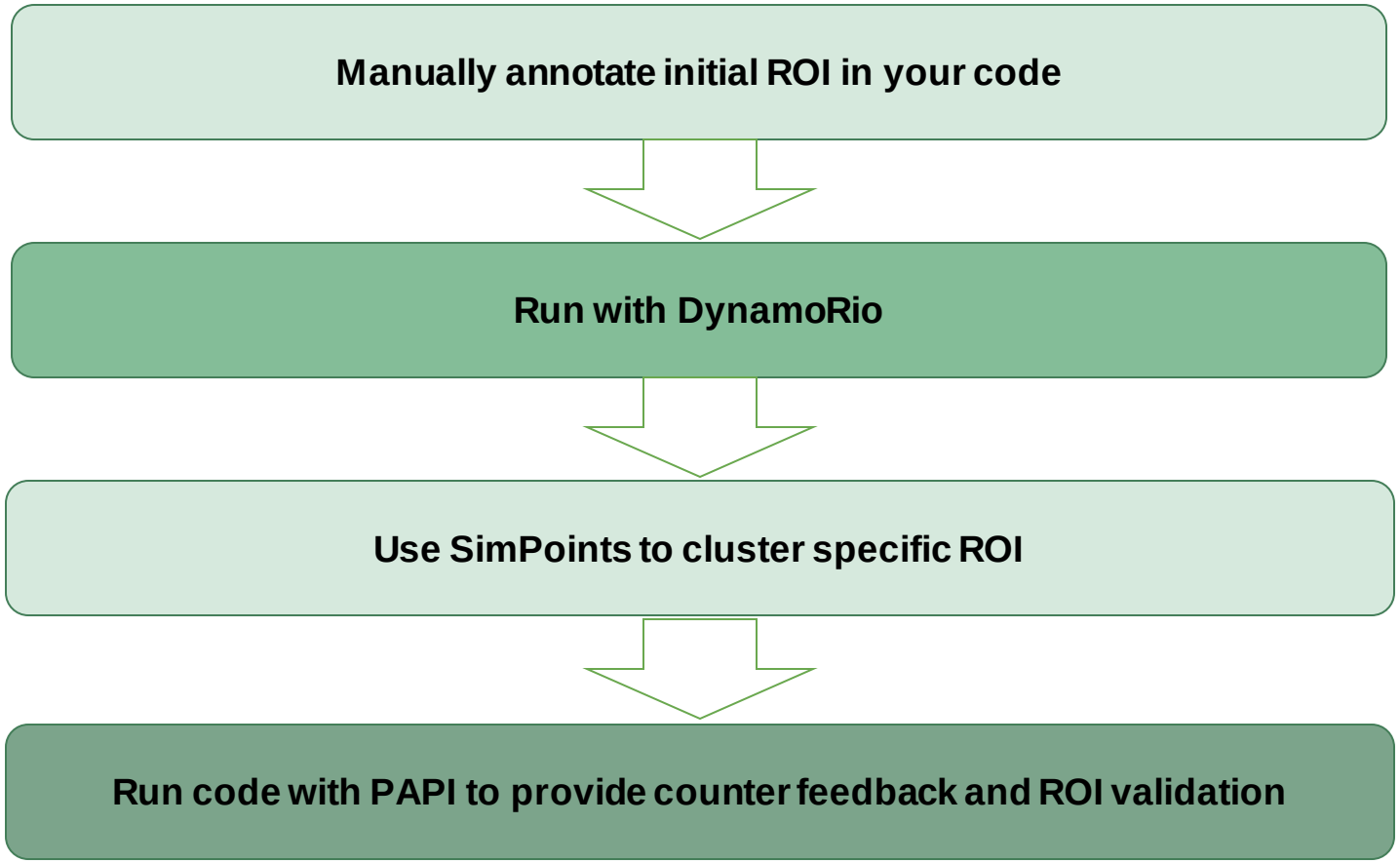
Synchronization Point

Synchronization Point

Synchronization Point

Based on work by Carlson, Trevor E., Wim Heirman, Kenzo Van Craeynest, and Lieven Eeckhout. "Barrierpoint: Sampled simulation of multi-threaded applications." ISPASS 2014

Barrier Points Workflow



Based on work by Miguel Tairum Cruz, Sascha Bischoff, Roxana Rusitoru,
"Shifting the Barrier: Extending the Boundaries of the BarrierPoint Methodology". ISPASS 2018

Why is the concept of BarrierPoints relevant for architectural simulation and OMPT?

- Gem5 has to be run with parallel configurations in an embarrassingly parallel fashion
- OMPT helps! it's a good way to extend and implement new BarrierPoint-like features
  - We envision that OMPT could be be used to automatically add regions of interest as well as trigger some of the analysis BarrierPoints uses (e.g., trigger DynamoRio emulation or PAPI counters)