gem5/SST Integration

What is SST?

The structural simulator toolkit (SST) is another computer architecture simulator, yet, unlike gem5, SST has been developed to explore *large*, *highly concurrent* designs. In particular, it has utility in helping researchers with interests in communication considerations between computer components and distributed system architectures.

The focus of its design is the holistic effects of protocols, networks, and other communication considerations that concern computer architects. It focuses considerably less on accurately simulating individual machines or components within machines.

SST uses the following nomenclature to describe its design:

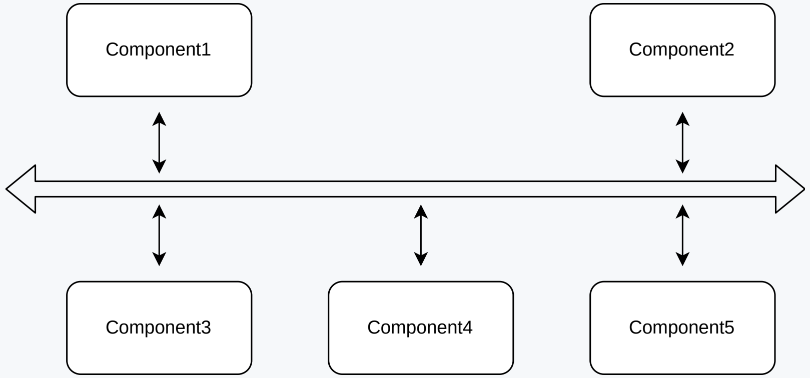
- **Components**: The individual elements of the system being simulated. The may contain multiple subcomponents which are specialized components subclass. As such, (subcomponents can contain other subcomponents. Using a computer cluster as an example, a component would likely be a node in the cluster.
- **Events**: Events are, at the most basic of levels, a generic interface for components to communicate with one another (through **ports** via **links**, see below). Each component has its own event handler which is tasked with understanding the events it receives. Simulations are typically events triggering components to send other events, thus creating a chain of events.
- **Ports**: The exposed entry/exit points for events between component. **Warning**: Unlike in gem5 a port does not connect directly to port. Ports are connected via **links**.
- **Links**: The connections between ports that allow events to be sent between components. Properties of these connections between ports are defined here (e.g., latency).

SST's design

In terms of software design and build considerations, the SST simulator is split between the **SST core** and the **SST elements library**. The core is the simulator itself but without any Components to. The elements library contains the components that can be loaded and run, in an SST simulation.

SST is parallel!

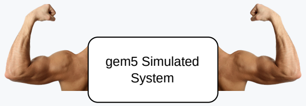
SST is highly parallelized Every component can be run as separate thread and use the SST core to communicate with other components. This means that SST is considerably more scalable that gem5. Grander simulations are possible grander hosts.



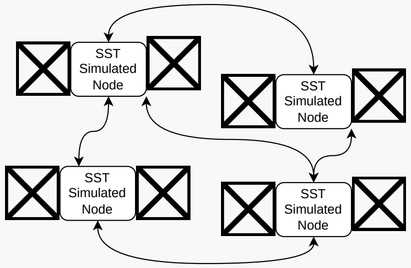
SST, in comparison to gem5

In comparison, gem5 lacks any real support for distributed systems or any task that requires lots of communicating via some established protocol. gem5 was never designed with such problems and systems in mind. Instead gem5 focused efforts on simulating the individual computer systems well. For example, gem5 has, and continues to, invest heavily in allowing relatively high fidelity modeling of cache hierarchies, and other microarchitectural details.

Additionally, gem5 is a single threaded application. While a user is always able create more more gem5 processes (one per simulated system), there's no framework allowing them to communicate with one another. Quite simply, gem5 cannot simulate large (e.g., supercomputer systems) in timescales that are useful or without coming at the cost of considerable accuracy.



One good simulated system



Many ok simulated systems connected together

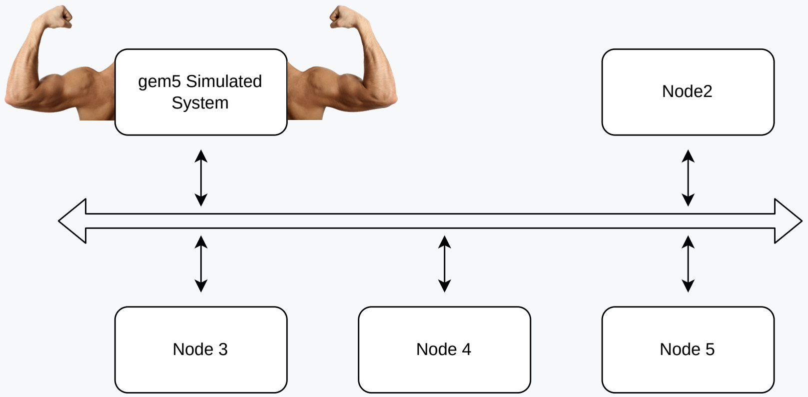
Why would you want gem5/SST integration?

To get the best of both worlds of course!

The general idea for having gem5/SST integration is that we can use gem5 to gather high-fidelity per-component data while using SST to simulate the larger-scale system interconnections.

The idea is to have *gem5 as a SST compoent*.

Note: At present this is just one gem5 component per SST simulation.
This is laregly ok as other SST components can be kept "dump" and left to simulate nothing more than communication from the wider system. Once a simulation is complete we can see both how a compnent fairs and how the system overall performs.



Ok then! Let's do it! To start, let's (not) install SST

Before using SST you must first install it... though this isn't very interesting so we'll use a docker container with sst already installed to save us the hassle.

The Dockerfile for this container can be found at util/dockerfiles/sst/Dockerfile. If interested you may use this for reference on how to install SST.

To enter the container, run the following command:

```
cd /workspaces/lpos2024
docker run --volume `pwd`:`pwd` -w `pwd` -it --rm ghcr.io/gem5/sst-env:latest
```

That should be all your need to do. You should now be in an environment with SST installed.

To have an gem5 component, we must first build gem5

To use gem5 as a "component" in SST, you need to build it as a library so it can by incorporated in into a CPP-based wrapper that allows for communication between SST and gem5. d

To compile gem5 as a library we first use `defconfig` to define the build:

```
cd gem5/
scons defconfig build/for_sst build_opts/RISCV
```

Here we are saying we want standard RISC-V build and for the sources and binary to be build in `build/for_sst` (this keeps is separate from the standard build).

Building the gem5 library

We then build gem5 as library by specifying `libgem5_opt.so` as the target. (If you're building on a Mac, it's not `.so` it's `.dynlib`).

```
scons build/for_sst/libgem5_opt.so -j8 --without-tcmalloc --duplicate-sources
```

Note: There are some funny build requirements here.
We must build the gem5 library without tcmalloc and with "duplicate sources". The reasons for this isn't important. They are needed for messy, legacy reasons. Please just remember to include these when building gem5 as a library.

Let's get to know SST better

While we wait for that complication...

SST and gem5 share a lot similar ideas and, sometimes confusingly, nomenclature.
Please keep in mind that SST components are more like gem5 SimObjects than gem5 components; events are more like gem5 packets sent over gem5 ports, and ports in gem5 are not like-for-like ports in SST. SST requires "links" between ports to connect them.

Like gem5 the SST configuration file is a Python file that describes the system design in terms of components (Simobjects), their parameters, and how they connect together.

Making a toy SST simulation

Here we're going to learn the basics of SST with a pre-built component called `example0`, the full type of which is `simpleElementExample.example0`. **Note**: we will skip how this is created and loaded into SST for now. This example component, unlike others, comes pre-loaded with SST so we needn't worry about the incorporation process.

`example0` is a very simple component with a single port to connect to another component (in our case we'll connect to another `example0` component). The `example0` component simulates a set number of events to the other component (we can think of these are spurts of communication from one component to the other). The simulation ceases after this set number of events have been sent.

To inspect any component loaded into SST we can use the `st-info` command.

```
st-info simpleElementExample.example0
```

If you do this the following should be returned:

```
ELEMENT LIBRARY 0 = simpleElementExample ()
Components (8 total)
   Component 6: example0
      Description: Simple Demo Component
      ELI version: 0.9.0
      Compiled on: Aug 19 2024 17:13:20, using file: example0.h
      Category: PROCESSOR COMPONENT
      Parameters (2 total)
         eventsToSend: How many events this component should send.  [<required>]
         eventSize: Payload size for each event, in bytes.  [16]
      Ports (1 total)
         port: Link to another component
      SubComponent Slots (0 total)
      Statistics (0 total)
      Profile Points (0 total)
      Attributes (0 total)

SubComponents (4 total)
```

A simple SST system with two `example0` components

The following code can be found in materials/05-Other-simulators/01-sst/01-sst-tutorial.py. We will be expanding it to create a full SST simulation.

```python
import sst


component0 = sst.Component("c0", "simpleElementExample.example0")
component1 = sst.Component("c1", "simpleElementExample.example0")
```

This is creating two `example0` components with names `c0` and `c1`. It should be noted that all SST components much have a unique name.

Note: A complete example can be found in the SST repository at `materials/05-Other-simulators/01-sst/sst-tutorial.py`.

Add SST components' parameters

Next we need to set the components' parameters with their `addParam()` methods:

```
param_set = { "eventsToSend" : 20, "eventSize" : 32 }
component0.addParams(param_set)
component1.addParams(param_set)
```

In this case each component is set simulate the sending of 20 events of size 32 bytes.

Link the SST components

Finally, we need to create a link between the two components' ports.

```
link0 = sst.Link("link_c0_c1")
link0.connect( (component0, "port", "1ns"), (component1, "port", "1ns") )
```

The above creates a link called `link_c0_c1` between the `port` of `component0` and the `port` of `component1`. The `"1ns"` is latency. In this case, the same `1ns` value is set for both directions.

We can already infer what this will simulate: each component will send 20 events, each of which will take 1ns to complete complete. Therefore, the simulation should take 22ns to complete.

Running the SST simulation

At this stage you can run your SST simulator with the following command:

```
sst sst-tutorial.py
```

This will output the following:

```
Simulation is complete, simulated time: 22 ns
```

While this configuration is very basic, it demonstrates how SST can be used to simulate a system.

Now back to to incorporating gem5

Hopefully your `libgem5_opt.so` has finished building by now. If so, we can now compile a gem5 component for SST and register it with SST.

In our work we want to use gem5 as a component to respond to events. This will be a bit more complex than the simple components we've seen so far, but the basic idea is the same.

We start by selecting the right Makefile for the build:

```
cd ext/sst
cp Makefile.linux Makefile
```

Building the gem5 component for SST

We then change `ARCH=RISCV` to `ARCH=for_sst` in the Makefile. This sets the target "architecture" to the we just built.

Then build with:

```
make -j8
```

You can tell from the build output that a gem5 component has been built and dynamically linked to SST. Let's go into a bit more detail about how this works before using it.

Understanding the SST-gem5 integration (well, some of it)

The `ext/sst/gem5.hh` file is relatively simple and gives a high-level view of how gem5 (or, rather, the gem5 library) can be declared and used as a component in SST.

```
class gem5Component: public SST::Component
{
  public:
    gem5Component(SST::ComponentId_t id, SST::Params& params);
    ~gem5Component();

    void init(unsigned phase);
    void setup();
    void finish();
    bool clockTick(SST::Cycle_t current_cycle);
```

This code defines a class `gem5Component` which inherits from `SST::Component`. The four methods methods `init`, `setup`, `finish`, and `clockTick` are overriden virtual methods from the `SST::Component` base-class and are called at different points in the simulation. So far this is very similar to how all SST components are defined.

The remainder of this class definition in `gem5.hh` are the methods used by SST to interact with gem5. You may look over this code and see how it works in
The important part are the MACROS are where our gem5 component links with the SST core.
They are part Element Language Interface (ELI) which is SST's API for registerint components and allowing for them to be dynamically loaded in SST simulations.

```
public: // register the component to SST
    SST_ELI_REGISTER_COMPONENT(
        gem5Component, // The component class
        "gem5", // The library SST will search for (in this case "libgem5.so")
        "gem5Component", // The compoenet name (used in the Python code to lookup the component)
        SST_ELI_ELEMENT_VERSION(1, 0, 0), // The version of the component
        "Initialize gem5 and link SST's ports to gem5's ports", // A description of the component
        COMPONENT_CATEGORY_UNCATEGORIZED // The category of the component
    )
```

The above shows usage of `SST_ELI_REGISTER_COMPONENT`. All SST components must be registered with SST using the this macro. When declared, and during compilation, SST will attempt to dynamically link with the library and wrap it as a SST component. Comments have been added here to make it clear what each parameter to this macro does here.

`SST_ELI_DOCUMENT_PARAMS` is used to declare the parameters of the component. In this case the gem5 component has a single parameter, `cmd`, which is the command to run gem5's configuration..

```
SST_ELI_DOCUMENT_PARAMS(
    {"cmd", "command to run gem5's config"}
)
```

Finally we have `SST_ELI_DOCUMENT_PORTS` which is used to document the ports of the component. In this case the gem5 component has two ports, `system_port` and `cache_port`, which are used to communicate with the gem5 system and CPU respectively.

```
SST_ELI_DOCUMENT_SUBCOMPONENT_SLOTS(
    // These are the generally expected ports.
    {"system_port", "Connection to gem5 system_port", "gem5.gem5Bridge"},
    {"cache_port", "Connection to gem5 CPU", "gem5.gem5Bridge"}
)
```

How does this gem5 simulation inside SST keep in-sync with SST?

For gem5 to work with SST they must be simulating with some common understanding of time to exchange information between one another at the right time. The short answer here is gem5 keeps in lockstep with the SST clock but let's look at the code that does so in `ext/sst/gem5.cc`:

```
bool
gem5Component::clockTick(SST::Cycle_t currentCycle)
{
    // what to do in a SST's cycle
    gem5::GlobalSimLoopExitEvent *event = simulateGem5(currentCycle);
```

`clockTick` is a virtual method part of the `SST::Component` class and is called on every SST clock tick. We use this to keep gem5 in sync with SST.

Navigating to the `simulateGem5` function we see the following:

```
uint64_t next_end_tick = \
    timeConverter->convertToCoreTime(current_cycle);

// Here, if the next event in gem5's queue is not executed within the next
// cycle, there's no need to enter the gem5's sim loop.
if (gem5::mainEventQueue[0]->empty() ||
    next_end_tick < gem5::mainEventQueue[0]->getHead()->when()) {
    return gem5::simulate_limit_event;
}
gem5::simulate_limit_event->reschedule(next_end_tick);
gem5::Event *local_event = doSimLoop(gem5::mainEventQueue[0]);
gem5::BaseGlobalEvent *global_event = local_event->globalEvent();
gem5::GlobalSimLoopExitEvent *global_exit_event =
    dynamic_cast<gem5::GlobalSimLoopExitEvent *>(global_event);
return global_exit_event;
```

This code figures out the gem5 `Tick` it will have simulate to to finish at the end of the SST's next clock cycle. The gem5 simulator then simulates to that tick and exits. gem5 then waits for SST to run its cycle and starts again

The process is as follows:

1. SST lets gem5 know the current cycle.
2. gem5 Figures out the tick it should be at for the next SST cycle.
3. gem5 simulates to that tick.
4. SST executes it's cycle then returns to step 1.

Let's run gem5 in SST

In materials/05-Other-simulators/01-sst/02-gem5-in-sst.py you will find a partially implement SST configuration script that we will build upon. Provided are the various parameter values.

A completed script for this exercise can be found in materials/05-Other-simulators/01-sst/completed/02-gem5-in-sst.py.

What we are going to try and create in this exercise is a computer system which gem5 simulates the processor and SST simulates the memory and cache.

Probably most notable of the parameters provided is at the end of the script:

```
cpu_params = {
    "frequency": cpu_clock_rate,
    "cmd": " ../../configs/example/sst/riscv_fs.py"
            + f" --cpu-clock-rate {cpu_clock_rate}"
            + f" --memory-size {memory_size_gem5}",
    "debug_flags": "",
    "ports" : " ".join(port_list)
}
```

These are the parameters we are going to pass to the gem5 component. We *have* to pass the `cmd` parameter as this is the command that gem5 will run to simulate the processor. The other parameters are optional and are used to set the frequency of the CPU, any debug flags, and the ports that gem5 will use to communicate with SST.

Note: Will continue with this tutorial. This markdown document is not finished yet.