Loupe: A Deadlock Visualization Tool

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1 INTRODUCTION

As one of the past course projects of ECE 6115, Loupe is a network deadlock visualization tool for Garnet2.0 that shows a graphical representation of the network when deadlock occurs and highlight the deadlocked flits.
Loupe consists of two parts:

- **Patch** to the Garnet source code allows Garnet to generate trace files containing the state of the network during simulation.
- **Visualizer** reads in the generated trace file, visualize the network and detects potential deadlocks.

2 MAIN FEATURES

2.1 Network Visualization

Loupe is able to visualize networks with Mesh topology, including routers, buffers and links. Loupe is also able to visualize all the flits in the network at every cycle of the simulation.

2.2 Deadlock Detection

Loupe is able to detect cycles in channel dependencies, which allows it to detect deadlocks in the network. There are two modes of deadlock visualization in Loupe:

2.2.1 Deadlock Snapshot Mode. In Garnet2.0, the simulation will halt and produce a message indicating potential deadlocks in the network when one or more flit has been stuck in the same router for more than a fixed threshold of cycles.
Loupe's Garnet patch uses this feature to obtain the state of the network, i.e. the information of every flit in the network right before the simulation ends. Then, Loupe will output the network state into a csv file called **deadlockSnapshot.csv**.
When the user opens this snapshot file in Loupe, Loupe will apply it's deadlock-finding algorithm on the obtained network state to find any deadlocks. If a deadlock is found, it will highlight the deadlocked flits and routers.

2.2.2 Cycle-by-Cycle Mode. Loupe also logs the state of the network for every cycle of the simulation. After the simulation stops, the Garnet patch will produce a csv file called **LoupeTraceFile.csv** that could be read by the visualizer, and the Visualizer could traverse through the network state during each cycle of the simulation to detect and visualize deadlocks.

3 INSTALLING LOUPE

In Lab 3, main components of Loupe: the patch and visualizer, are included in the lab files, either through updating your old copy of gem5 or cloning a fresh copy of gem5.

3.1 Patch

The patch files are located in **gem5/src/mem/ruby/network/garnet2.0.**

3.2 Visualizer

The visualizer is located in **gem5/Loupe_Visualizer**.

4 ENABLING AND LAUNCHING LOUPE

4.1 Enabling Loupe in Garnet Simulations

To enable Loupe during simulation, add **--enable-loupe** after the garnet simulation commands. Here is an example command which will enable loupe:

```
./build/Garnet_standalone/gem5.opt configs/example/garnet_synth_traffic.py
--network=garnet2.0
--num-cpus=64
--num-dirs=64
--topology=Mesh
--mesh-rows=8
--sim-cycles=20000
--synthetic=uniform_random
--vcs-per-vnet=4
--inj-vnet=0
--injectionrate=0.02
--routing-algorithm=random_oblivious
--enable-loupe
```

This will enable Garnet to generate trace files used by Loupe visualizer. **Note that without this option, the trace files will not be generated.**

4.2 Launching the Visualizer

To launch the visualizer, cd into Loupe_Visualizer folder and launch the visualizer by typing **python driver.py**. The visualizer main window will appear.

5 USING LOUPE: A STEP-BY-STEP EXAMPLE

5.1 Encountering Deadlock

In Lab 3, you are asked to implement several deadlock avoidance methods. However, if your implementation is incorrect, deadlocks would still occur in the network during simulations.

In current Garnet implementation, when a flit has been stuck inside a virtual channel (VC) for more than 5000 cycles, the simulator determines that a deadlock may have occurred and halts the simulation, as shown in Fig.1. The 5000 cycles is a parameter called deadlock threshold that could be adjusted.

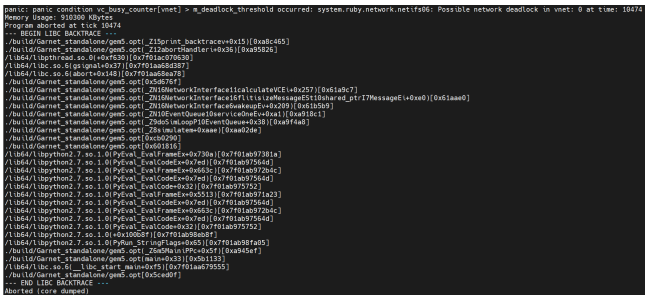


Figure 1: Garnet ends the simulation when it determines a deadlock has occurred.

5.2 Visualizing Deadlock using Loupe

If you have enabled Loupe during simulations, Loupe generates two trace files in the gem5 folder when the simulation is terminated due to deadlock: **deadlockTraceFile.csv** and **LoupeTraceFile.csv**.

- **deadlockTraceFile.csv** contains the network state, including every flit in the routers, at the cycle when the simulation is terminated. **Note that Loupe only generates this file when Garnet determines that a deadlock has occurred.**
- **LoupeTraceFile.csv** contains the network states for each cycle of the simulation. **Note that this file is always generated, regardless of whether the simulation is terminated or successfully completes.**

5.3 Using Deadlock Snapshot Mode

5.3.1 Main Window. After launching the visualizer, the main window will appear as shown in Fig.2.

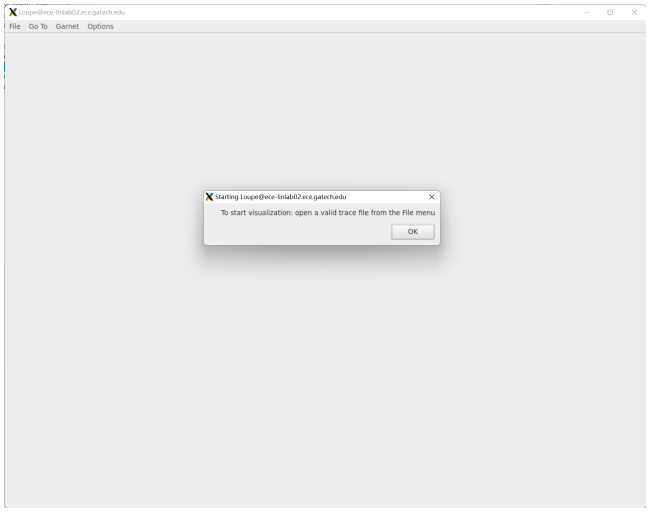


Figure 2: Main Window of Loupe Visualizer

5.3.2 Opening Deadlock Snapshot File. To open the snapshot file, click **File->Open Deadlock Snapshot**. A prompt will appear to let you select a trace file, as shown in Fig.3. Choose deadlockTraceFile.csv in gem5 folder and open it.

Typically, the size of the snapshot file will not exceed 1 MiB, and opening this file will not take more than 5 seconds.

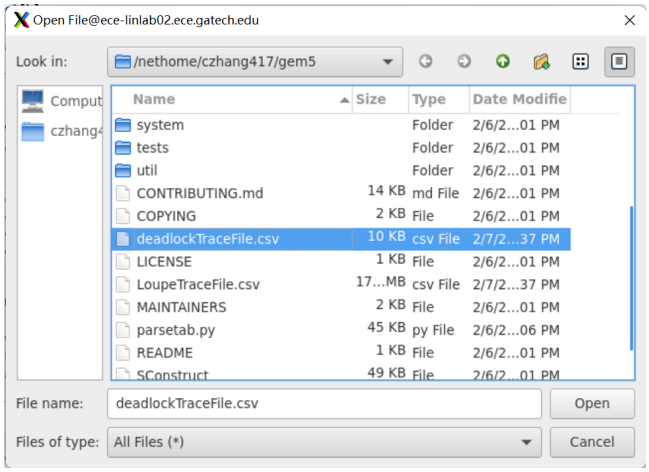


Figure 3: Opening deadlock snapshot.

5.3.3 Deadlock Snapshot Mode Interface. The user interface of deadlock snapshot mode contains three parts: Overall network view, close-up core view and flit information table.

5.3.4 Network View. The top number of the network view indicates the exact cycle when the simulation is terminated. Main network components, including the routers and links are visualized, as shown in Fig.4.

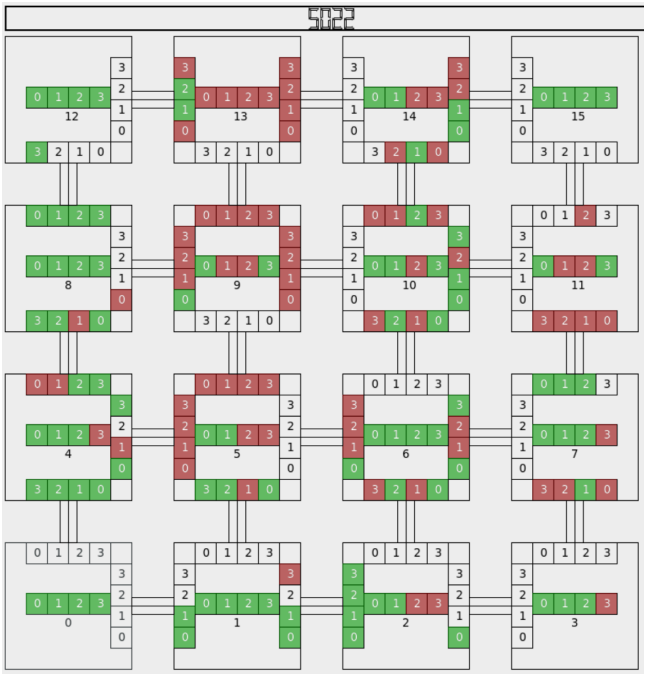
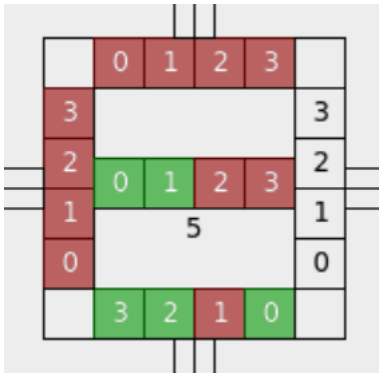


Figure 4: Visualization of network topology, links and routers.

Each larger square represent each router, with the router ID at the lower middle. Inside each larger square are the small squares, which represent VCs.
The locations of the VC boxes represent their port directions. For example, the 4 small boxes at the upper part of the router box represents the North buffer of router 5.
The number for each small box represent which VC it represents in each buffer.



(a) Visualization of Router with North, South, West, East and Core buffer.

(b) Cycle Number at the deadlock is shown at the top of the interface.

Figure 5: Network Visualization

In this mode, the flits that are involved in deadlock(s) are shown in red. However, note that **both green and red boxes represent flits, while transparent boxes represent empty VCs**.

5.3.5 Close-Up View. The close-up core view contains the zoomed-in view of a router and options to select the router and buffer to be displayed, as shown in Fig.6.

5.3.6 Flit Information Table. To view the information of a single flit in a router:

(1) Select the router (core) where the flit is under **Close-Up Core View**.
(2) Select the buffer (North, South, East or West) where the flit is under **Buffer Information**.

The information for flits inside every VC in the buffer contains:

- Flit ID: Each flit in the network are assigned a ID during the simulation.
- Flit Type: Some flits are segmented part of a packet. However, this lab only deals with single-flit packets.
- Flit Route: The source and destination router IDs of the flit.
- Flit Outport: The current direction that the flit is going to travel, which is determined by the routing algorithm.
- Cycles in Current VC: The number of cycles for which the flit has stayed inside this VC.
- Current Location: Whether the flit is inside a router (InUnit) or a link (InLink). This should always be InUnit for flits inside routers.

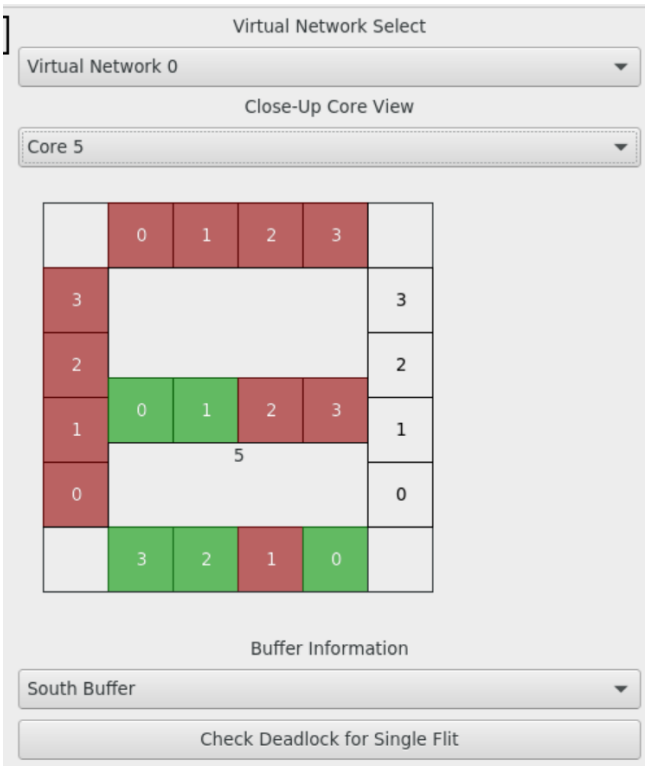


Figure 6: Close-Up View, Core (Router) and buffer selection

	VC 0	VC 1	VC 2	VC 3
Flit Id	358744832	359465472	359203328	360120832
Flit Type	Head + Tail	Head + Tail	Head + Tail	Head + Tail
Flit Route	3 -> 9	2 -> 5	2 -> 13	2 -> 8
Flit Outport	West	West	West	West
Cycles in Current VC	5000	4989	4993	4979
Current Location	InUnit	InUnit	InUnit	InUnit

Figure 7: Detailed info about the flit in each VC.

5.3.7 Checking Deadlock for One Flit. In Deadlock Snapshot mode, you could also highlight which routers are involved in the deadlock for a single flit. To do so, you need to:

(1) Identify the flit that you are interested in and obtain its Flit ID.
(2) Click on **Check Deadlock for Single Flit**, a prompt will appear on the screen as shown in Fig.8. Enter the flit ID that you want to check deadlock on.
(3) The Visualizer will indicate whether the flit is deadlocked. If so, it will highlight the routers involved in the deadlock, as shown in Fig.9.

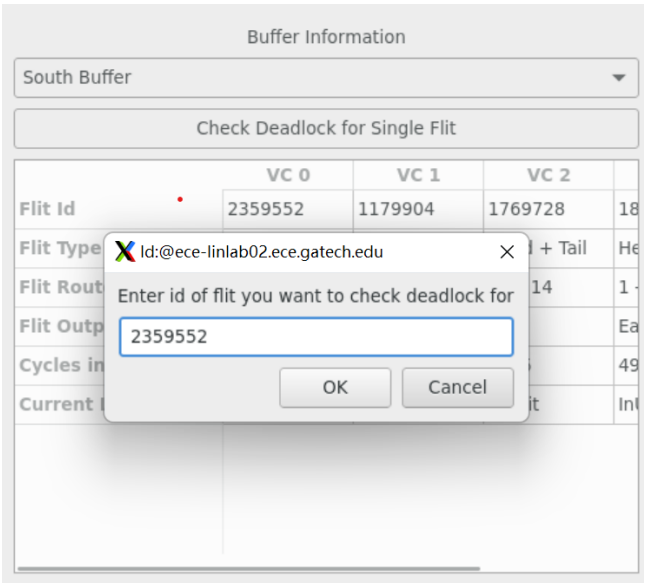


Figure 8: Prompt for entering the flit ID.

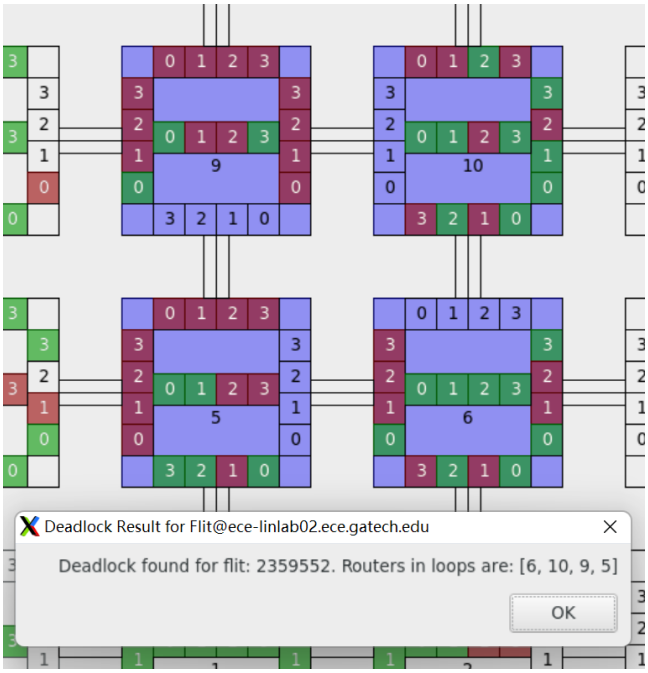


Figure 9: Result after checking a single flit.

5.4 Using Cycle-by-Cycle Mode

5.4.1 Opening Trace File. To open the trace file, click **File->Open Trace**. A prompt will appear to let you select a trace file, as shown in Fig.10. Choose LoupeTraceFile.csv in gem5 folder and open it.

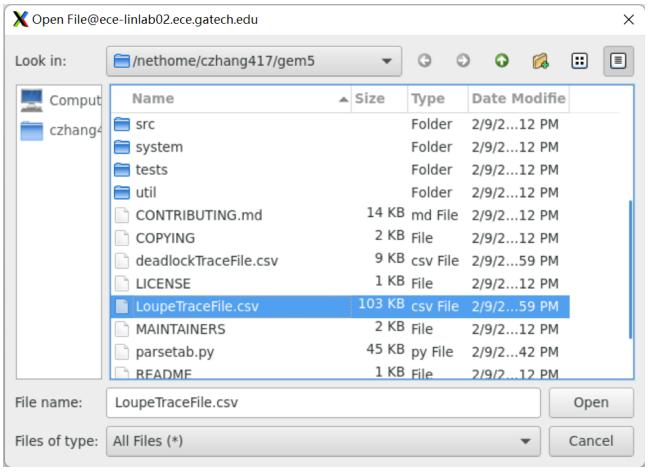


Figure 10: Opening trace file

5.4.2 Cycle-by-Cycle Mode Interface. The user interface of Cycle-by-Cycle Mode, as shown in Fig.11, is similar to Deadlock Snapshot mode, except for a few differences.

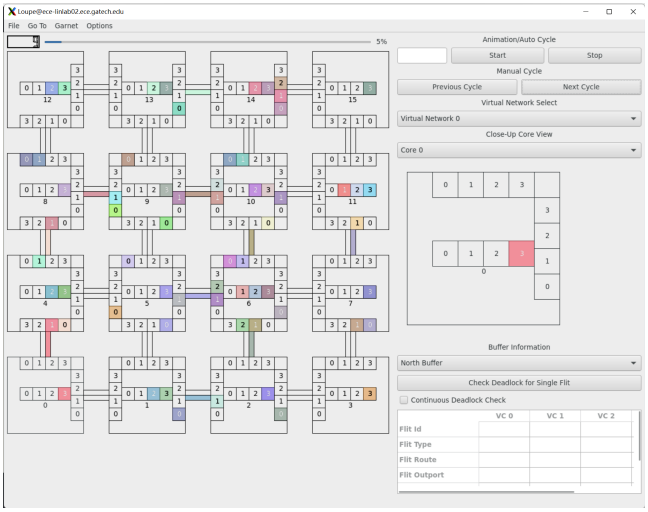


Figure 11: Cycle-by-Cycle Mode Interface

5.4.3 Network Visualization. Network visualization is mostly the same, as shown in Fig. However, the flits are colored in random colors instead of red/green. The flits in the links are also visualized in Cycle-by-Cycle mode.

5.4.4 Manual Cycle. To switch between network states for each cycle, click **Next Cycle** or **Previous Cycle** to switch between the current cycle of the simulation that the Loupe is visualizing.

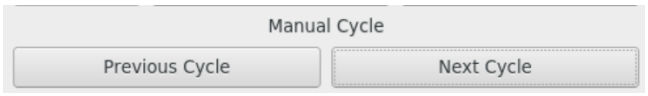


Figure 12: Manual Cycle Mode

5.4.5 Continuous Deadlock Check. Ticking this box will allow Loupe to check whether all the flits in the network of the current cycle have been deadlocked.
When you go through the next cycles, if one or more flits in the current cycle has been deadlocked, a message-box will pop up, indicating that the network has encountered deadlock. The deadlocked flits will be colored red.
Note that the deadlock checking algorithm could be slow over large number of flits or larger network sizes, such as 8x8 Mesh.

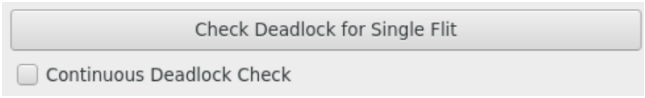


Figure 13: Deadlock Check checkbox

5.4.6 Auto Cycle. Auto Cycle allows Loupe to automatically go through cycles until reaching a user-designated end cycle. To start the auto cycle, enter a valid cycle number in the input box at the left of "Start" button, then press start.
Loupe will automatically advance to the next cycle and visualize the network for that cycle until the end cycle had been reached.
Please note that currently Auto Cycle does not work due to changes being made to Loupe's underlying implementation. This document will be updated in the future.

6 DEBUGGING TIPS

To debug your deadlock avoidance implementation, for each flit that are deadlocked, you may want to check:

(1) Which VC the flit is in? In some deadlock avoidance implementations, you may use escape VCs.
(2) What is the route of the flit? Is the flit on its expected route for its routing algorithm?
(3) Which turn is the flit going to take? You could deduce this based on the which buffer the flit is in and the outport of the flit.

By obtaining these information, you could determine whether your routing algorithm or deadlock avoidance scheme is working correctly.

7 CONTACT

As of Spring 2022, this tool is being actively maintained by Canlin Zhang. If you encountered any problems using Loupe, feel free to contact him at czhang417@gatech.edu.

8 APPENDIX: DETAILED DESCRIPTION OF FEATURES (FROM THE ORIGINAL REPORT)

This documentation will go through all the features our Loupe implementation by introducing the functionalities and instructions on every feature in Loupe.

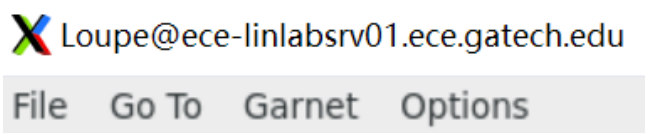


Figure 14: Top Menu of Loupe

8.1 Menu Items

8.1.1 Main Menu.

When we open Loupe, we will see a menu as shown in Fig.14. There are four items, File, Go To, Garnet and Options:

8.1.2 File Menu.

This Menu has three options:

- **Open Trace...** This let the user open a trace file which is generated by Garnet after each simulation. The trace file's default name should be **LoupeTraceFile.csv**. This trace file contains the locations of all flits in the network for every cycle in the simulation.
  To load the file, click the button, and a pop-up window should appear. Navigate to the trace file you want to load into Loupe, and it will start loading.
  For larger trace files, it might take longer time. For example, the typical load time for a 40 MB trace file will not take more than 20 seconds. If the trace file loads successfully, a pop-up window should appear, indicating success.
  Opening Trace let Loupe enter Cycle-by-Cycle Mode, which will be explained later.
- **Open Deadlock Snapshot...** This let the user open a deadlock snapshot file, which contains the information of all the flits in the network when Garnet detected a deadlock. (A flit exceeding deadlock threshold cycles) The snapshot file's default name should be **deadlockTraceFile.csv**. This file is only generated by Garnet after each simulation if the simulation is aborted because of deadlock detection.
  To load the file, click the button, and a pop-up window, similar to the one that appears when loading a trace file, will appear. Navigate to the snapshot file you want to load, and it will start loading.
  Since the snapshot file is not large, it will typically be loaded instantly.
  If snapshot file is successfully loaded, Loupe will enter Deadlock Snapshot Mode, which will be explained later.
- **Quit** This will close the Loupe application.

8.1.3 Go To Menu.

This Menu has three options:

- **Cycle 0** This let Loupe go back to cycle 0 and display the network status at cycle 0 of the simulation. **This only works when Loupe is under Cycle-by-Cycle mode after a trace file has been successfully loaded.**
- **Cycle 500** This let Loupe go to cycle 500 and display the network status at Cycle 500 of the simulation. This only works when:
  1. Loupe is under Cycle-by-Cycle mode after a trace file has been successfully loaded.
  2. The simulation duration is larger than 500 cycles.
- **Cycle...** This let Loupe go to a cycle number designated by the user and display the network status of that cycle of the simulation.

The underlying implementation of Go To Menu has been untouched, and may not work as intended due to the major changes we introduced to Loupe.

8.1.4 Garnet Menu.

This Menu has two options:

- **Generate Garnet Run Command** This allows user to generate simulation commands for Garnet2.0, configurations include Topology (Currently only support Mesh), number of CPUs, Topology-specific parameters (Rows and Cols for Mesh), injection rate, traffic pattern and routing algorithms. To generate a command, click the button, and a pop-up window will show up. Adjust the parameters as you need, then press Create Run Command button. Another pop-up window containing the generated command will show up.

- **Help** This currently does not do anything.

The underlying implementation of Garnet Menu has been untouched, and may not work as intended due to the changes in user directories and binary names of Gem5 simulator.

8.1.5 Options.

This Menu has two options:

- **Set Animation Speed** This allows user to set the speed for automatic cycle progression (explained later) in Cycle-by-Cycle mode.
  To adjust the animation speed, click the button, and a pop-up window will show up. Adjust the parameters as you need.
- **Set Deadlock Notifications** This allows user to set up the cycle threshold for Loupe to show a flit as being deadlocked. The original Loupe implementation has its own way to calculate the time a flit has been stuck in the same VC, and the if the user-set threshold has been reached, Loupe will mark the flit with certain colors.
  However, this feature is complete removed from our Loupe implementation, since we have our own algorithm to detect deadlock for each flit.

8.1.6 Operating Modes Explained.

As mentioned earlier in the report, there are two modes for our Loupe implementation: Deadlock Snapshot mode and Cycle-by-Cycle Mode. This document will explain the details of these two modes by the elements appeared in the Loupe GUI.

8.1.7 Deadlock Snapshot Mode.

After loading a deadlock snapshot, Loupe will enter this mode. The right part of the UI should look like Fig.15. Here are the UI elements in Deadlock Snapshot Mode:

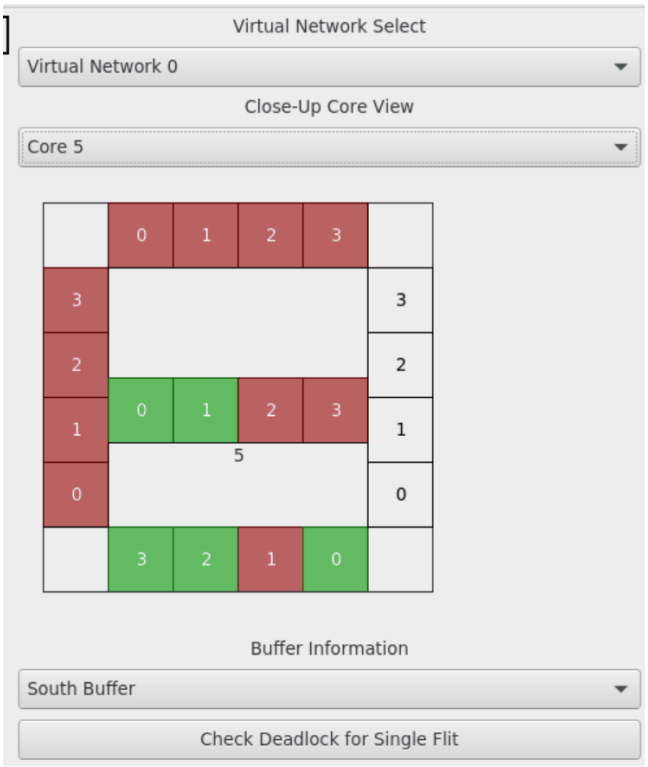


Figure 15: Right part of the Deadlock Snapshot Mode UI

- **Coloring of the flits** All flits that has been stuck in the same VC for over 5000 cycles will be colored red, while others will be colored green.
- **Virtual Network Select** This allows the user to change the display between multiple virtual networks. However, this feature has not been tested for our implementation.
- **Close-Up Core View** This allows the user to select a core in the network for close-up inspection. The ports and buffers of the designated core and flit visualization will be shown below.
  To designate which core to view, click on the drop-down list below "Close-Up Core View", and select from the list of cores in the network.
- **Buffer Information** This shows detailed information for each flit inside a specific buffer, for example, the flits inside the North Buffer of Core 0. To select which buffer to view in a specific core, click on the drop-down menu below "Buffer Information", and select from the list of buffers in the core. (Some cores may have less than 5 ports.)
- **Check Deadlock for Single Flit** This enables the user to check whether a specific flit has encountered deadlock using our algorithm. To check for deadlock, click on the button, and a pop-up window should appear. Enter the ID of the flit you want to check deadlock for, and click OK. If the flit has deadlock, there will be a pop-up window showing the routers that are involved in the deadlock, and the corresponding routers in the network visualization will be colored blue. Otherwise, the pop-up windows will just say the flit does not have deadlock.
- **Flit Table** The table at the bottom of the UI shows information for each Flit in all VCs inside a buffer. The information includes Flit ID, Flit Type (Head/Tail/Head+Tail), Flit Route (source and destination router), Flit Outport, Cycles in current VC and Current Location (InUnit or InLink, should always be InUnit)

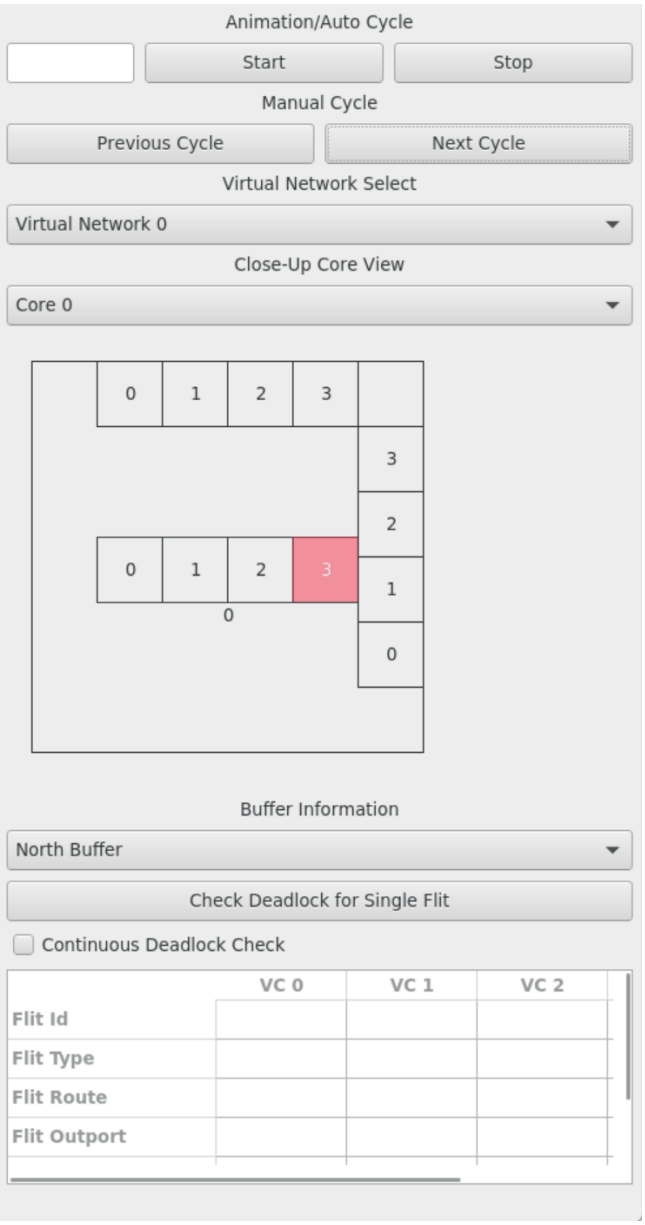


Figure 16: Right part of the Cycle-by-Cycle UI

8.1.8 Cycle-by-Cycle Mode.
After loading a trace, Loupe will enter this mode. The right part of the UI should look like Fig.16. Most of the UI elements are the same

as in Deadlock Snapshot Mode. The elements unique to Cycle-by-Cycle mode are:

- **Coloring of the flits** The colors of the flits are randomly assigned. However, if user enables deadlock check mode, flits that are deadlocked will be colored red.
- **Current Cycle Display** The current cycle of the network that Loupe is visualizing will be shown on the top-left of the UI.
- **Continuous Deadlock Check** This allows Loupe to check whether all the flits in the network of the current cycle have been deadlocked. To enable this mode, tick the tick-box before "Continuous Deadlock Check". Then, if you go through the next cycles, if one or more flits in the current cycle has been deadlocked, a message-box will pop up, indicating that the network has encountered deadlock. The deadlocked flits will be colored red.
  We did not enforce deadlock checking for every cycle by default. This is because our deadlock checking algorithm could be slow over large number of flits.
- **Manual Cycle** This allows the user to go to the next or previous cycle of the simulation, and the network visualization will be updated to display the network information of the next or previous cycle. Previous or Next Cycle button will have no effect if the beginning or the end of the simulation has been reached.
  Please note that Previous Cycle button may cause the Continuous Deadlock Check functionality to break. The deadlock calculation for each flit still works correctly, but the coloring of deadlocked flits does not.