

# CREATION OF AN ONLINE VIRTUAL CISCO ROUTER LEARNING ENVIRONMENT

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## ABSTRACT

Online learning environments are an important aspect to many University courses. They allow flexibility in student approaches, and permit students from a range of backgrounds to take part in education. This paper considers an online learning environment which provides a VLE (Virtual Learning Environment) style approach teaching Cisco router configuration techniques, such as might be required in a course teaching the CCNA curriculum.

## KEYWORDS

Advanced Technology in Education and Training, VLE, LinuxZoo, Virtualisation.

## 1. Introduction

The use of online learning environments provides learners with a flexibility to select a learning methodology which best supports their study style and personal constraints. Attendance mode students can choose to attend practical sessions, work at home, from work, or even on the move, while still being able to access the same resources. This in turn matches the current student expectations of flexible learning, which is a shift that has been detectable for more than a decade [1]. Some subjects may map quickly to flexible learning using static web pages and simple interactive content. However this paper is concerned with a complex subject domain that gives students direct access to virtualized computing hardware, coupled with a tutorial environment which measures student progress and which confirms to the student when each task is completed correctly. This environment is known as LinuxZoo, and was developed by one of the authors at Edinburgh Napier University for teaching operating system and network administration.

The LinuxZoo VLE, effectively provides a microworld-style learning environment [2]. This gives the student access to a selection of virtualized hardware platforms, such as User Mode Linux [3] running Fedora, dynamips [13] running Cisco IOS router emulations, and QEMU [4] running Windows 2008. This paper specifically focuses on the dynamips emulation capabilities, which

emulates a number of Cisco routers including the 7200 router platform.

## 2. The Virtual Cisco Router Learning Environment in a Glance

Cisco routers are used in the construction of many computer network topologies. Routers are one of the devices involved in forwarding network packets from one device to another, i.e. “routing” packets from the source of the information to the ultimate destination. Cisco routers can be configured in a range of ways, depending on the network topology being implemented, and managing this complexity requires training.

Cisco provides materials for training at a variety of levels, including industrially recognized curriculums such as CCNA and CCNP [5]. The training material is based on theoretical knowledge presented online or in books, reinforced with extensive lab-based activities. These labs are primarily designed to occur in supervised practical sessions, where trainers can identify student errors and guide them to solutions. Without supervision it is challenging for the students to overcome errors, to have high confidence that their solutions are error-free, and to be able to ask questions to allow them to fully understand the theory. This could be an obstacle to offering Cisco-style tutorials in a flexible learning framework.

The work discussed here is primarily focused on supporting flexible learners through the use of virtualization/cloud technologies. There are a number of products available to allow users to run virtualized Cisco routers on their own computers, such as GNS3 [6], Dynagui [7], and Packet Tracer [8]. These can be effective simulators or emulators to help experience the behavior of using real Cisco routers without having to actually purchase the real hardware. However these require the user to have a reasonably high performance computer, and to install applications and store data locally. Indeed, for virtualizations involving operating systems, this could run into many tens of gigabytes of data.

A cloud solution allows users to run the virtualized router emulations from any computer with a browser. These run on remote servers, so use no local resources. This can promote low energy usage, as well as being

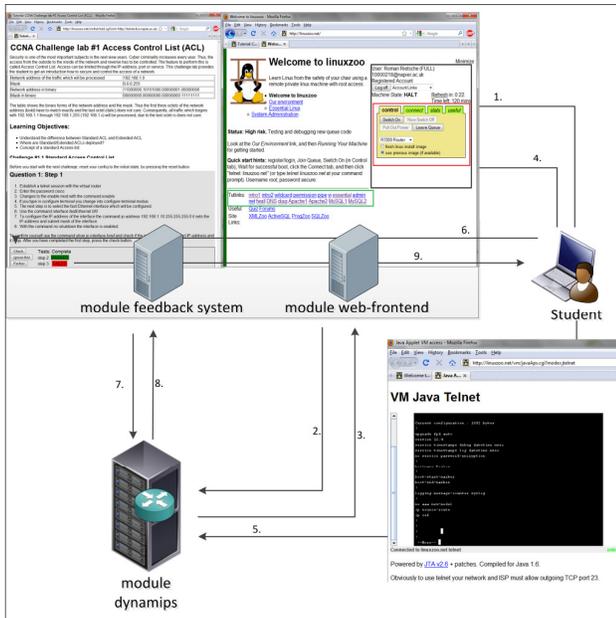


Figure 1. Architecture of the virtual router environment

immediately available (nothing to download and install) and offering high availability (as system problems are centrally solved). It is also very portable, allowing users to study from multiple computers but still access the same data.

This paper examines our locally developed router emulation environment, named Linuxzoo, which is also designed to offer Cisco-style tutorials in a flexible mode. Figure 1 shows the architecture of this VLE. It consists of three modules: a web frontend, the dynamips emulator, and the feedback system. The module web-frontend is the management interface for the students, in which the virtual instances can be created, stopped, or restarted. It also provides access to the tutorials. This interface is accessed via the student's web browser. The dynamips module provides the backend infrastructure, in which the virtual routers run, as well as maintaining persistent data on each session.

Students use the VLE by taking ownership of a virtualized router, logging onto the router's console connection (a command line interface) using telnet or a similar tool, and then attempting to answer tutorial questions by creating configurations entered via the console.

The feedback system is a key element of this learning environment, presenting the tutorials to the students and providing algorithms which check that each tutorial question has been completed correctly. This checking is done by automatically comparing the output of commands executed in the virtualized router against regular expressions stored with each tutorial question. The most important and unique function of the system, in contrast to other Cisco-related VLEs on the market, is that the original IOS from Cisco is used in the emulation (thus giving the student a highly realistic router interface) which

**Question 1:**

1. Establish a telnet session with the virtual router.
2. Change to the enable mod with the command *enable*.
3. Enter the password *cisco*.
4. To change into the terminal mode type *configure terminal*.
5. The next step is to select the fast Ethernet interface which will be configured.
6. Use the command *interface fastEthernet 0/0*.
7. To configure the IP-address of the interface the command: *ip address 192.168.1.10 255.255.255.0* it sets the IP-address and subnet mask of the interface.
8. With the command *no shutdown* the interface is enabled.

To confirm yourself, exit the configure mode and change to the privileged mod and use the command *show ip interface fastEthernet 0/0* and check if the interface has the correct IP-address and it is not administratively down. After you have completed the first question, press the check button.

Check	Tests: Complete
	IP-address: FAILED
	shutdown: FAILED

Figure 2. Cisco Router tutorial in LinuxZoo

is coupled to an accurate and efficient automatic feedback mechanism that evaluates if the student has completed the tasks correctly or not.

The feedback system functions by establishing an additional telnet session to the AUX port of the virtualized router, executing commands to view the current state of the router configuration, and comparing the output of the commands using regular expressions stored in the web interface. This process is triggered using “check” buttons presented as part of the tutorial interface (Figure 2). The AUX port is effectively a second console port, usually used for modem connections, but which operates as a console port with minor IOS configuration changes.

The advantage of this technique is that the student can be logged on the virtual router via the console while in the background the configuration is checked via the AUX port. As the commands to be executed which evaluate the configuration are easily configurable for each question by the trainer, the checking can be both fast and robust.

One challenge of this approach is that dynamips only has partial AUX port support. In particular it only supports the 7200 platform. Additionally the way messages are written to the port can interfere with methods for producing the automated feedback. Unfortunately the developer of the dynamips code no longer appears active. The solution here was to change the dynamips code ourselves to support AUX ports on all platforms, and alter the way the interface worked to allow for easy automated access. These changes have been posted on one of the dynamips forum sites [9].

The students only receive feedback on whether their current router configuration correctly or incorrectly matches the requirements of the current question, so this is perhaps lacking the elaboration issues of formative feedback [10]. Thus there is no simple automatic mechanism to provide any information on why a solution is wrong, and this forces the students to be self-directed in diagnosing why their current solution is incorrect (e.g. search the internet, ask their fellow students or in a supervised tutorial the tutor for help). Another approach is to write the automatic feedback checks to be diagnostic, so that the names of each check directs the student to the

reason why that test failed, and thus suggestive on the remedial action needed by the student to fix their mistake.

The realism offered by providing emulated devices allows the users to experience the full range of device capabilities is important to provide the users with an illusion that they are truly using real hardware, while the tight coupling of tutorial, automated feedback, and emulation environment is expected to enhance the experience of flexible learners. These learners may be studying without direct supervision, so require immediate feedback as to their progress and errors in order to provide them with an experience reminiscent of that found in a supervised session.

### 3. Costs

According to [11] a Laboratory facility is important to teach the CCNA curriculum, as it provides students with the flexibility to experiment and explore the issues and challenges associated with network equipment, network communication and computing. Networking classes often involve theoretical and technical concepts delivered in a lecture environment, combined with practical work in supervised laboratory training.

To provide a high standard in teaching, students should have access to the network equipment and to PCs. There can be considered to be three requirements to achieve a high standard in teaching within practical labs [12].

1. Laboratories should be available outside the supervised tutorial hours.
2. Students should be able to start, pause and continue their exercise over a period of time.
3. Access to the learning environment should be safe, secure and available on students demand.

The physical Cisco labs in the School of Computing (6 CCNP Pods, 6 ADTRANS, plus assorted wireless and VoIP devices) represent an investment over the last 5 years which exceeds £500 per student FTE (Full Time Equivalent). Additional costs are incurred on a regular basis due to hardware failure and changes to teaching.

However by taking into account other non-core usage of this equipment, such as ad-hoc evening courses, actual costs are nearer £250/FTE.

In contrast the LinuxZoo environment teaches over 100 students per year, and uses server hardware on a 4 year replacement plan. It has hardware costs of £7.07 per FTE, supplying one virtual instance per student, and a practical session group size of up to 50 simultaneous students. As the hardware for most of the time outside timetabled sessions has only about 5% hardware utilization, it would be easily scalable to more students or more virtualizations per student.

LinuxZoo was specifically written to run on low cost server systems for large numbers of students. It monitors student usage so that idle virtualized machines are shut down automatically, and students wanting to use a virtual machine are queued in the system until the resources are available. The queue is priority based, so timetabled events can take priority over ad-hoc usage. Free users are also currently supported directly from the internet, though have less priority than our own students. This contrasts with other commercial technologies, where resources have to be carefully managed and monitored to prevent resource exhaustion or poor system performance. This makes LinuxZoo a useful cost-saving technology to support our networking courses. It is also easily extendable, and additional servers can be added when needed to form a pool of virtual machines.

### 4. Performance

In times of green IT (and limited budgets), the use of resources has to be as efficient as possible. For this reason a performance evaluation of the virtual router learning environment was carried out. The two measurements examined were CPU and memory usage. The CPU used here was a Xeon 5110 (four cores) clocked at 1.6GHz with 2GB of physical memory and 16 GB of swap space. The evaluation covers the performance of simultaneously starting 2, 4, 6, or 8 routers.

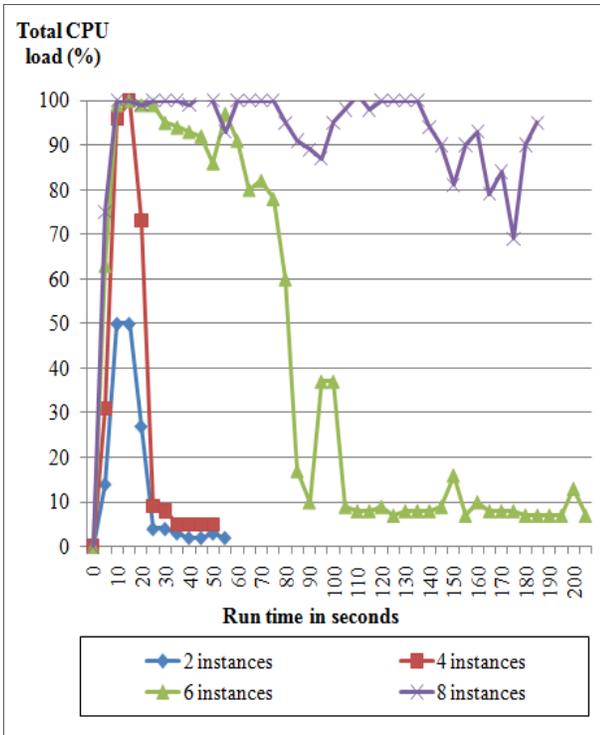


Figure 3. Graph of CPU usage during the evaluation

The IOS of a Cisco router was never designed to run as multiple instances on a single CPU, and when idle will be using up CPU time. Hence, in the default case a single virtual router will use 100% of a core even if the router is relatively idle [13]. To overcome this issue, the developers of dynamips introduced a feature called *idle-PC*. This takes a value calculated by dynamips representing an instruction memory address where, when reached, indicates a good place to pause and wait for interrupts [13]. This makes CPU usage much lower, especially when running multiple instances.

Figure 3 shows CPU usage during the evaluation, which demonstrates that up to 4 routers starting simultaneously can be handled by this system. There is a considerable amount of disk thrashing during startup, and simultaneous startup can be considered the worst case performance in our system. 6 routers take a considerable time to settle, due to a high degree of swap space activity. 8 routers never settle due to excessive swapping. This seems to indicate that CPU performance is not a significant limiting factor in providing virtualized routers in LinuxZoo, even on the relatively dated hardware used in these experiments. Instead having sufficient memory is critical to good performance. The memory requirements can be seen more clearly in Figure 4. Only with 6 or 8 routers is swap space needed. Each virtual router was allocated 256MB of simulated memory. In this case 6 is probably the maximum number of virtualisations which can fit onto this hardware with this configuration.

Dynamips does have a clever scheme to improve memory performance. It does this by allowing the IOS to be loaded as a memory mapped file, and for this to be

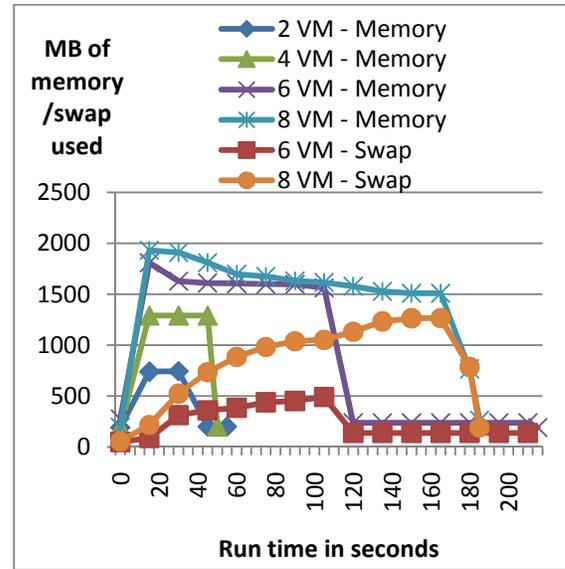


Figure 4. Graph of Memory and Swap usage

shared between all routers which are using the same IOS. Effectively this saves memory usage by whatever the size of the uncompressed IOS is (in this case 93MB) times the number of routers in use. This technique, called a *ghost image* in dynamips [14], makes configuration a little more complex. This was then activated and the experiment repeated for the 8 router scenario. The results of this compared with the non-ghostimage 8 router experiment can be seen in Figure 5. With this new configuration some swap is still needed, but 8 routers settle to 16% CPU time within 150 seconds. This makes the use of ghost images a worthwhile complexity provided the virtualizations are sharing the same IOS, platform, and memory size.

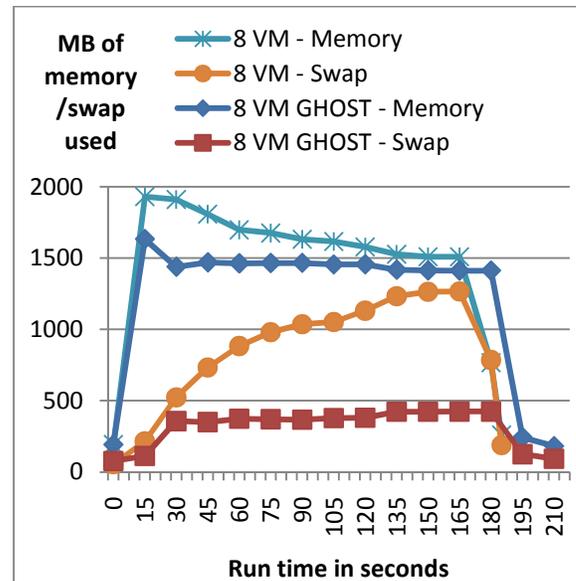


Figure 5. 8 router experiment with ghost imaging

## 5. Educational Benefits

It is useful to be able to perform an analysis of the educational impact of this system. This was investigated by experimentation, where five students followed specially designed tutorials using real Cisco hardware, and five other students followed the same tutorial structures using the virtual Cisco router learning environment in LinuxZoo.

This experiment is designed to allow us to explore the actual difference in the student experience between how Cisco tutorials would traditionally be taught using real hardware and Cisco-style tutorials, in comparison to that of students using the virtualised environment supported by the Linuxzoo integrated feedback system. The content, style, and format of the tutorials undertaken were otherwise identical in both groups.

Moreover, both groups were further divided into; three students who have experience in configuring Cisco routers and two who had never had contact with a Cisco router before. After finishing the tutorial, all groups completed a questionnaire.

In Cisco-style practicals, the style of the exercises is very much focused on hands-on practical exercises, but relies on accurate completion of each step of a process. Errors in a step, even a trivial typing error, can easily be made by a student and go undetected until a much later step indicates that a problem exists. It can then be difficult for the student to identify the problem without assistance. In a flexible study mode without immediate and accessible tutor support, such errors could lead to poor performance and low student performance. Thus the immediate feedback mechanism of Linuxzoo should offer significant learning advantages. It should also help stop students proceeding to the next step of a tutorial in the belief they had completed that step, when in reality their solution was incorrect.

### 5.1. Evaluation approach

The tutorials used in the evaluation approach consisted of two challenge labs, in which in the first consisted of a step by step guide to ACL configuration, where every command was explicitly given (similar in style to a Cisco Academy tutorial). In the second challenge lab the students had to use the knowledge studied in the first lab and adapt it to solve a specified networking problem.

The experiment allowed the measurement of the learning achieved from the first tutorial by measuring the performance in the second lab. This was done by examining the mistakes that the students made in the second lab.

Furthermore, the self-efficacy of the students was measured by examining the result of a survey completed after the tutorial, combined with how often the students asked for help during the evaluation and how often the check button was pressed by the students using the virtual environment. Afterwards the data on training success and

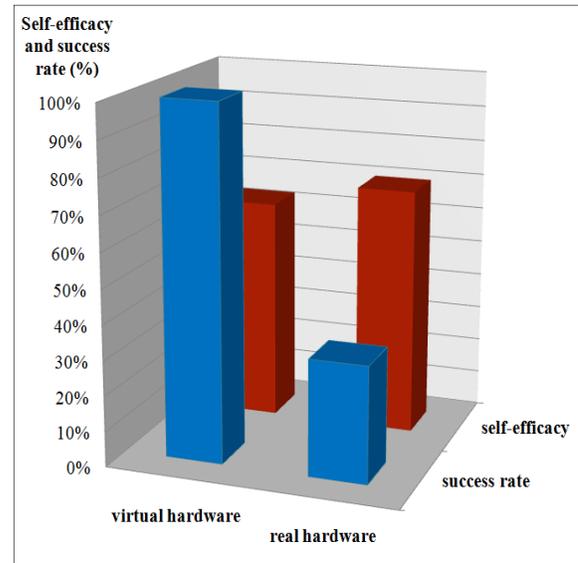


Figure 6. Link of self-efficacy and success rate of the group with previous knowledge on configuring a Cisco router

self-efficacy were linked together and the relationship was examined.

### 5.2. Discussion of the findings

The purpose of linking self-efficacy (in this case the self belief in one's ability to solve router configuration problems) and training success of the students was to provide information on whether the students who had high self-efficacy actually made fewer mistakes in processing the tutorial. Reference [15] carried out a number of studies in perceived self-efficacy and how it could be evaluated, and was used in the construction of this experiment.

Self-efficacy is related to how one would judge their ability to deal with a prospective situation. Students who think they will perform well are more likely to do well in contrast to students who think that they might fail. Students' should judge their self-efficacy as high while being successful in performing a task, but repeated failures may lower their perceived self-efficacy. The following figures demonstrate how the students rated their self-efficacy in terms of their ability after the second challenge lab in our experiments.

If one considers the group of students who have had experience with Cisco routers previously, students using the system judged their self-efficacy at 63% (Figure 6) and had a lab completion rate of 100%. Hence, the students could be said to have underestimated their skills. However, the analysis of the students' actions (i.e. how often the check button was pressed) showed that the check button was pressed on average 19 times. This might be an indication that the students at first received negative feedback and therefore rated their self-efficacy lower. The student group who used the real hardware rated their self-efficacy at 70% (approximately the same as the first group) but instead had a success rate of 33%.

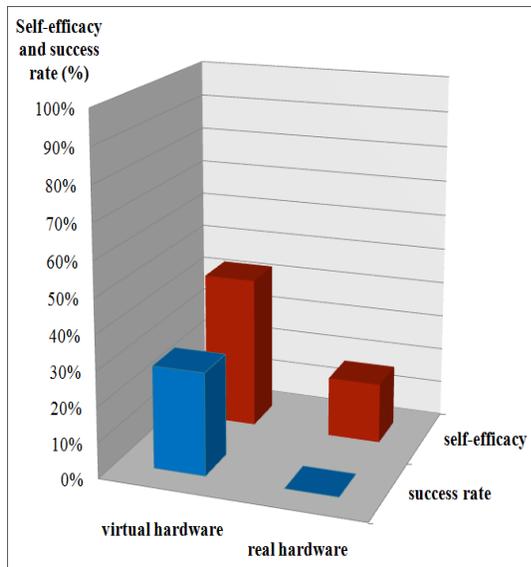


Figure 7. Link of self-efficacy and success rate of the group who never had any contact with a Cisco router before

This second group appears to have overestimated their skills. Nevertheless by using real hardware and having the students evaluate their achievement themselves (no check button on the real hardware) it is unknown how many attempts were required to get to the final answer. However, examining the configurations of this group of students showed that some configuration commands were mixed up, in the wrong order, wrong or apparently forgotten, which might be an indicator that the students also made several changes in trying to complete the task. Nevertheless these students rated their self-efficacy slightly higher than the first group.

A different picture emerges when repeating the experiment with the group without previous knowledge. In this case both groups of students overestimated their capabilities. The students using the virtual router environment rated their self-efficacy at 43% and had an actual success rate of 17% (Figure 7) in contrast to the students using the real hardware, who judged their self-efficacy at 29% and the actual success rate was 0%. The group who used the virtualized hardware pressed the check button on average only six times, however it has to be considered that due to the difficulty of the task and the limited time allowed to perform the tutorials, the students were able to spend only a limited time on this final task.

When the configurations of the hardware-based group are examined, it is clear that the students did not even have a basic understanding of the configuration commands, which they should have learned of in the step-by-step initial tutorial.

The average success rate of the knowledge-lacking groups was very low in general, but this is perhaps not surprising in that by definition they lacked the required skills. What is important in all experiments is that the virtualized hardware approach with its integrated tutorial environment consistently allowed the students to perform

better than the students who used a more traditional tutorial approach using real hardware.

## 6. Conclusion

It can be concluded, that if the Idle-PC value is set correctly, the usage of CPU time is decreased to a level which makes router virtualization an attractive approach to consider for supporting teaching. Dynamips needs a lot of memory, and each virtual router in this experiment used was allocated 256MB, which equates to around 400MB each including simulation overheads. However with careful use of some of the memory management features 8 routers can run in just over 2GB. Thus, it can be concluded that if dynamips is used for a virtual Cisco router learning environment, an IT infrastructure is needed which provides enough memory to cope with a large amount of virtual routers. However memory costs are relatively insignificant to the cost of a server, and low-power servers with 16GB or more of memory are comparatively cheap.

From the student-based experiments it can be concluded that there is a tendency for students with previous knowledge and the use of the LinuxZoo system to judge their self-efficacy slightly lower than the students with previous knowledge who used the real hardware. This might down to discouragement on receiving messages from the system indicating again and again that they did not answer the question correctly until the right answer was given (which was also found out in the studies of [15]). However, the students who had never had experience with Cisco routers before interestingly overestimated themselves, and in term of self-efficacy it did not matter if the virtual environment or the hardware was used.

Overall the evaluations showed that students using the LinuxZoo system seemed to make fewer mistakes and have a measurable benefit from receiving the automatic feedback.

A future improvement for the evaluation would be to enlarge the tutorials to cover more of the Cisco CCNA tutorial material, and conduct experiments with more students to minimize statistical error. Furthermore, it has to be considered that there are many ways to write a tutorial, if a different tutorial style were created, the results of the evaluation may be measurably different.

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