

Development of Autograder For Competitive Programming Using Contestant PC As Worker

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Abstract—Competitive programming is a computer science competition where the contestants compete to solve computer science problems by writing a program which satisfies the problem constraints. Autograder is used to grade contestant solutions automatically in real-time. Usually autograder is deployed in many computers to increase grading performance. In this work, contestant computers are used as worker to run autograder. By using contestant computers as worker, the number of worker will be proportional to the number of contestant submissions, thus increasing grading performance. Every contestant computer has different specification and can affect grading fairness. To keep grading fairness, contestant's solution and jury's solution executed in contestant worker and compared to check whether contestant's solution satisfies problem constraints. This work tested by simulating grading process in contestant computers. The testing result indicates that using contestant computers as worker gives performance improvement in the grading process.

Index Terms—competitive programming, online judge, autograder.

I. INTRODUCTION

Competitive programming is one of the most popular competition in computer science field. In competitive programming competition, contestants are asked to solve computer science problems correctly and as fast as possible. Some institute and organization often organize competitive programming competition periodically. Some big companies like Google and Facebook organize competitive programming competition annually. Competitive programming competition supported by online judge system. Usually, online judge system is a web based application where contestants can read the problems, create clarifications, submit their solution, and watch the scoreboard. Currently, the most popular online judge are Codeforces, URI Online Judge [8], Uva, and SPOJ.

In order to grade contestant submissions, online judge system has a subsystem called autograder. Contestant submissions which are source code in certain programming language will be graded by autograding system by compiling the program and executes compiled program using test-cases that have been prepared by juries or problem setter. According [14], this grading method is called black-box grading. By using autograding system, the grading process can be done automatically and juries don't have to evaluate contestant submissions manually. In order to increase the number of contestant submissions in certain amount of time, juries usually deploy autograder

in many computers. In order to run autograder in many computers, the juries need to prepare many computers with the same specification to keep the fairness of grading process.

Currently, almost every competitive programming competition use online judge system to support the competition and use many computers to run autograder in order to improve grading performance. Every computer that runs autograder is called worker. Grading performance is defined as the number of submissions graded in certain amount of time. Even though autograder is deployed in many computers, the grading performance is often not enough to evaluate contestant solutions in real-time because the number of contestants is increasing. Furthermore, the number of computer to deploy autograder affects the procurement cost that juries need to be incurred. Therefore, a new grading system is needed to increase grading performance without increasing procurement cost that needs to be incurred.

When competing in competitive programming competition, the contestants usually use their personal computer to write the solutions. Every contestant computer usually has sufficient specification to compile and execute contestant submissions. Therefore, contestant computers have the ability to run autograder program and evaluate contestant submissions.

II. RELATED WORK

There are some popular online judge systems that have been used to organize competitive programming competition. Some online judges offer additional features like discussion forum, training gate and rating system. Nowadays, most of online judges are deployed as web applications and use specific computers to grade contestant submissions. There are many types of competitive programming competition rules. Most of online judges only support specific competition rules.

One of the most popular competitive programming competitions is ACM-ICPC competition where the competition uses ICPC rules. In ACM-ICPC competition, contestants compete in groups of three people. Every group has the same amount of problems to solve, and the score is determined by the number of solved problems and time penalty. There are many online judges that support this competitive programming rules. The most popular online judge that supports this type of competition

is DOMJudge. DOMJudge is very popular because it has many usefull feature, easy to use and open source.

Currently, most of online judge use autograder to evaluate contestant submissions. According to [11], autograder is a system that compiles, executes and evaluate source code. Evaluates source code manually takes three minutes while using autograder only need ten seconds. By using autograder, contestants can receive grading feedback faster and reduce the work that need to be done by juries. Basically, the autograder evaluate the source code by compiles the source code, and executes the compiled program using predefined test-cases. The output of contestant's solution program compared to the predefined test-case and then graded. This evaluation method is called black-box grading [14].

We need to consider security aspect when developing autograding system. Competitive programming contestants might submit source code that contain dangerous code. According to [9], there are several attacks that can be made by contestants, such as submitting compile bomb code, submitting code that destroy autograding environment, and submitting code that access forbidden computer's resource. In order to prevent such things, autograding system must execute contestant's code in isolated environment called sandbox.

There are several ways to create isolated environment such as using virtual machine and containerization. By using virtual machine, one can create isolated operating system inside host computer. Virtual machine uses hypervisor to emulate computer hardware and run its own operating system. In Linux based operating system, there is a feature called KVM that make it possible to create hypervisor as a process in Linux [10]. We can use virtual machine to isolate the execution of contestant's code. However, by using virtual machine, we need to boot a new operating system each time we evaluate contestant's subission. This booting process takes so much computer's resource and reduces grading performance.

Another way to create isolated environment is by using container. Container is different from virtual machine. Container gives isolation in software level without hypervisor [12]. By using container, we can isolate process execution without boot a new operating system. Container works by using some Linux features such as chroot, namespace and cgroup. By using chroot, we can isolate filesystem of Linux process [13]. Container uses Linux feature called cgroup to limit process resources. By using cgroup, we can limit memory usage, CPU usage and disk IO usage of running process [10]. In order to hide other process, user, and network from a running process, container uses a Linux feature called namespace. By using namespace, we can isolate a Linux process from other process, so the running process not aware of the existance of other process. Instead of virtual machine, most of autograding system use container to isolate grading process. This method is used because it is more lighter and faster than virtual machine.

III. METHODOLOGY

A. Time and Memory Measurement

In competitive programming competition, every problems has time and memory constraints. Contestants are asked to solve the problem by writing program that satisfy the constraints. According to ICPC rules, when contestant's solution exceeds the problem constraints, the solution is rejected and the contestant get time penalty. Thus, autograding system need to tell whether contestant's solution exceeds the constraints or not. The problem is, every computer has different performance when executing a program. The same program might run faster in one computer and slower in another computer. Currently, most of online judge system uses identical computer to evaluate contestant submissions. By using identical computer, the same program expected to run at the same duration and consume the same amount of memories.

Contestant computers have different specification and performance. We cannot force the contestants to have identical computer. Thus, we need new time and memory measurement method. The performance of a computer is determined by its specifications such as CPU clock speed and operating system. We can tell the computer performance by its specifications. However, besides CPU clock speed and operating system, there are so much other factors that affect computer performance such as temperature, cache size, the program itself, and many other factors. Thus, determining computer performance by its specification is very hard and not feasible to do.

$$R_{contestant} < (1 + \gamma) \times R_{jury} \quad (1)$$

In this work, we compare contestant's solution and jury's solution. Contestant's solution considered satisfying the problem constraints when the memory and CPU usage of contestant's solution not exceeding jury's solution. Sometimes, contestant solution's memory or CPU exceeds jury's solution a little bit because the implementation is different. We add tolerance factor (γ) to tolerate this problem. Contestant's solution is considered satisfying problem constraints when the Equation 1 is fulfilled. When evaluating contestant's solution, the worker compiles and executes contestant's solution and jury's solution. After executes the solutions, the worker compares the memory and CPU usage of the execution and determine whether the contestant's solution satisfy problem constraints.

B. Load Balancing

We need to distribute grading jobs to worker evenly in order to increase grading performance. There are several load balancing method that we can use to distribute grading jobs evenly. The easiest way to distribute the jobs is by making each contestants to grade their own submissions. In this work, we didn't use this method because this method creates security vulnerabilities.

The other way distribute grading jobs is by using push-based load balancing method. In push-based load balancing, the online judge server choose the worker to do the grading jobs. By using this method, every contestant doesn't know which

submission they grade, thus can increase system security. To improve system security, we can also grade every submission multiple times. In order to implement this method, we need the status of all workers. This method is pretty hard to implement because we need to poll the worker status periodically and choose the best worker to evaluate the contestant submissions.

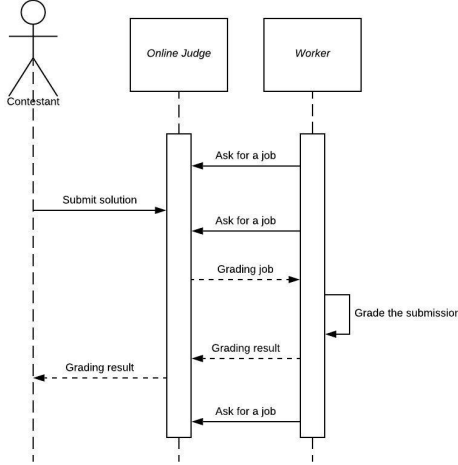


Fig. 1. Pull-based Load Balancing.

In this work, we use pull-based load balancing method. By using this method, we don't have to poll the worker status periodically. The worker will poll the jobs from server periodically and evaluate them when there is a job that ready to be evaluated. Fig. 1 depicts this method mechanism. This work is easier to implement than push-based load balancing method and has the same advantages.

C. Evaluating Submission In Isolated Environment

In order to isolate the evaluation process, we use containerization method. We compile and execute contestant's submission inside lightweight container. This container is created by using several Linux features and system calls such as cgroup, namespace, chroot and setrlimit. We use cgroup to monitor and limit the CPU and memory consumption of running process. The worker kills the program when the CPU or memory usage is exceeding the limit. In order to isolate the host's user, process and network, we use Linux feature called namespace. By using namespace, the processes inside isolated environment will not aware of any process, user or network in the outside of its own environment. In order to isolate filesystem of a process, we use chroot system call. Beside isolating the filesystem, we also need to bring some files from host environment into the isolated environment. We bring some of host filesystem into the isolated environment by using mount system call. We also limit the process limit by using setrlimit system call. By using setrlimit system call, we limit some process resources such as the number of child processes, the stack size, the number of open files and the size of file created by that process. Fig. 2 depicts how isolated environment is created.

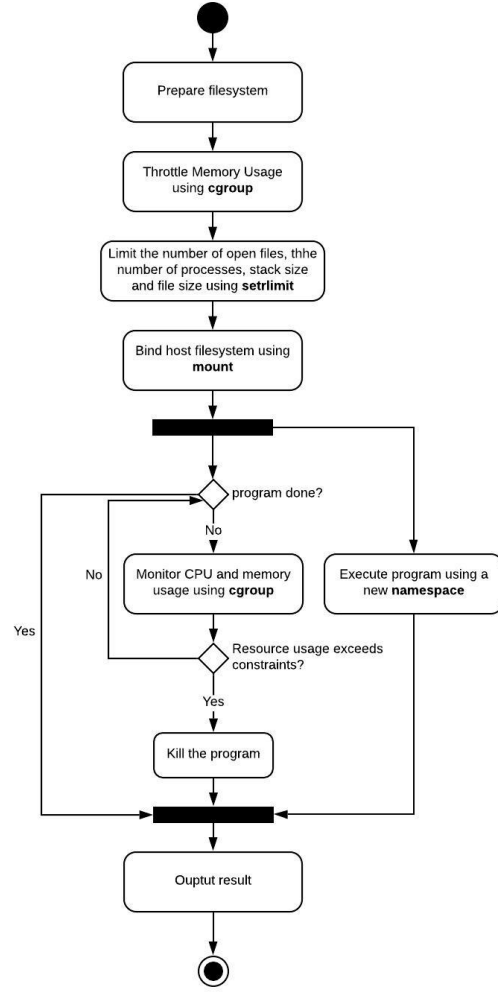


Fig. 2. Sandbox Activity Diagram.

D. Program Compilation

In order to evaluate contestant's submissions, we need to compile and execute the submitted source code. To compile the source code, we need a specific compiler. Every worker should have the same version of compiler. The same compiler with different version can produce different output. In order to keep the fairness of grading process, we need to distribute the same version of compiler to all workers in the system. In this work, we distribute the compiler in the autograder program to every worker. Every worker compiles the source code inside an isolated filesystem that has been installed with the same version of compilers.

E. Obtaining Problem Test-case

F. Handling Reverse Engineering Attack

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- Use either SI (MKS) or CGS as primary units. (SI units are encouraged.) English units may be used as secondary units (in parentheses). An exception would be the use of English units as identifiers in trade, such as “3.5-inch disk drive”.
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a) *Positioning Figures and Tables:* Place figures and tables at the top and bottom of columns. Avoid placing them in the middle of columns. Large figures and tables should span across both columns. Figure captions should be placed below the figures; table titles should appear above the tables. Use the abbreviation "Fig. 3", even at the beginning of a sentence.

TABLE I
TABLE TYPE STYLES

Table Head	Table Column Head		
	Table column subhead	Subhead	Subhead
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^aSample of a Table footnote.

Figure Labels: Use 8 point Times New Roman for Figure labels. Use words rather than symbols or abbreviations when writing Figure axis labels to avoid confusing the reader. As an example, write the quantity "Magnetization", or "Magnetization, M", not just "M". If including units in the label, present them within parentheses. Do not label axes only with units. In

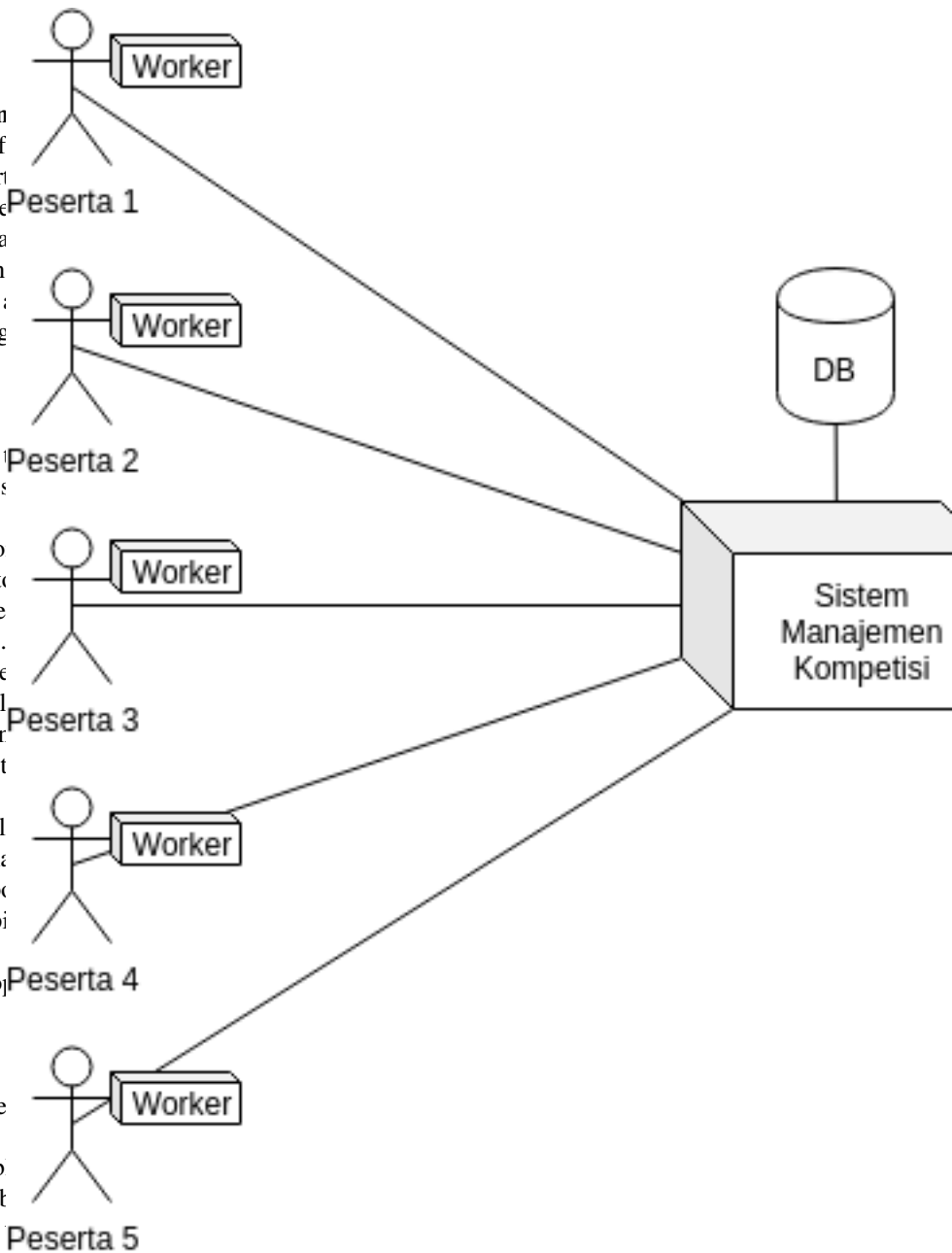


Fig. 3. Example of a figure caption.

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ACKNOWLEDGMENT

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REFERENCES

- [1] TODO.
- [2] TODO.
- [3] TODO.
- [4] TODO.
- [5] TODO.
- [6] TODO.
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