Remote Collaboration Potential in STEM Education using Bare Machine Computing Research

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Abstract*— Bare Machine Computing (BMC) is a paradigm used in programming applications to run on a Bare Machine. It consists of a CPU, Memory, and I/O without an Operating System and resident mass storage. It utilizes an Application Development model software that interfaces directly with the hardware. It also has potential as a powerful teaching and research tool in undergraduate STEM programs, notably Computer Engineering and Computer Science. Before the COVID-19 Pandemic, researchers used the University lab environment, and Bare Systems connected via LAN/WAN. The Pandemic restrictions put members of the research team in different locations. Hence, the researchers adopted a Remote Collaboration model of Concurrent Participation, Communication, and Development for Bare Machine to continue this research. This paper discusses the advantages and disadvantages of moving the BMC research entirely online and measures needed to address the Configuration of BMC Development Environment, Communication, Collaboration, and Diverse Skill Set. The paper covers online technical research because most literature concentrates on only online survey research's benefits and drawbacks. This paper also addresses BMC application in presenting STEM subjects to students, mainly undergraduate students. Finally, the paper includes remote research that fulfills the Department of Education (DOE) requirements of student access.

***Keywords*— Bare Machine Computing, Online Research, Operating Systems, STEM, DOE**

I. Introduction

The "No Operating System" concept of the Bare Machine presents challenges for conducting research using conventional laptops, desktops, and other computing devices. A Bare Machine executes software without any hard disk and kernel. There are no different privilege levels, and a Bare Machine executes all software in the user space. Presently, most development and debugging tools are specific to developing software on an Operating System. Therefore, these OS-specific elements are not compatible and unusable on a Bare Machine. In BMC, the researchers/developers build the application first on a system with an OS installed and test it on the QEMU emulator [26]. BMC researchers developed rudimentary debugging tools on the bare device to trap error conditions during execution, which required to read hex dumps and calculate address displacements in the bare workspace. Hence, the challenge of conducting the research.

Despite the challenges, the BMC paradigm has also produced opportunities for building undergraduate students' competency in learning/research. Discoveries through BMC research teach information technology subjects such as loaders, device drivers, assembly language, high-level programming languages, network protocols, and APIs. BMC researchers have been able to apply and demonstrate the experiments used in BMC research to undergraduate studies and guide undergraduates in their learning and research utilizing the BMC paradigm.

The Bare Machine paradigm has some very distinct characteristics. A BMC user carries the required application suite on a removable device, such as a flash drive, and can connect to any available bare device without any ownership. Before the pandemic, the research and development were carried out exclusively in the BMC laboratory environment, locally hosting bare machines containing various application development projects. This BMC research has successfully produced many applications [1]-[7] on bare machines in the BMC laboratory, some of them being the following:

a) Bare Text Browser: BMC research produced a Bare Text Browser, a self-contained, self-managed, and self-controlled application handling memory management and a new API that communicates directly with the hardware and manages its threads.

b) VOIP (with IPSec): BMC research proved that Voice Over Internet Protocol (VOIP) did not need an operating system

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c) Webservers (TLS): BMC Research has produced bare Web Servers that can communicate with each other. Researchers have developed a standard BMC Web Server module to work on a Bare Machine.

d) Split Servers (Protocol Split): BMC research did TCP protocol splitting by using two bare servers. One of the servers was a connection server and a data server splitting the TCP protocol into its connection and data phases, executing these phases on different machines during a single HTTP request.

e) Email Client: BMC research developed an email server working on bare machines. This email server developed was multi-threaded and allowed multiple users at any given time.

f) SQLite (Database): BMC research transformed and added SQLite to the list of applications that operate on a bare machine. The DB engine lends several levels of abstraction beyond the standard OS. Therefore it is heavily dependent on system calls.

g) Multicore Web Server Architecture: The first BMC webserver was single-core and only 32 bit. Later the BMC paradigm migrated to multicore and now compatible with 64-bit architecture.

h) IPSec: The IPSec baseline research suggested designing future versions of IPSec for high-performance or high-security bare PC applications and devices such as security gateways.

i) Gateways and Routers: BMC research has adapted APIs working with gateways and routers compatible on a bare PC using a six to 4 gateway, with IPv4 and IPv6.

These accomplishments make it possible to present the inner workings of operating systems, networks, protocols, binary executables, and devices in a manner that can be easily understood by a student. For example, from the memory dump in the application, students can learn how data is stored in memory and trace the actual value present in any memory address during debugging. BMC research can be a useful teaching tool for computer science and engineering STEM Education. It dissects the executable and interacts with the bare device, which can be observed in real-time by the STEM student. This education transcends the classroom. The pandemic restrictions made in-person research and education impossible, so a new approach was required to continue the research and teaching. With all the accomplishments and potential for further discoveries and their application to undergraduate research, the BMC researchers continued with remote research.

Remote research is much like working remotely as an employee of a corporation. There are many online resources for remote work, and many of the options free. Also, online education has been an option for some time. Therefore, most universities with online programs provide remote login access to academic services such as blackboard and library services. The online library resources [8] and other digital content is available to their faculty and students but under-utilized by many undergraduate students for research purposes. The conventional reason is that students do not understand how to utilize it. The librarian is a crucial participant for online education to impact and increase teaching presence [15]. Studies involving preservice teachers found increased awareness when exposed to reliable information online and, overall, developing their digital skills [16]. The librarian should be leveraged by the instructor to guide students in searching and accessing articles, papers, essays, and other research.

Another resource is videoconferencing tools that allow collaboration between instructors and students in groups and one-to-one. However, for the multitude of strength and support of various videoconferencing tools available today, the online world would not have witnessed the burgeoning growth and peerless popularity. Due to the data explosion the online universe is experiencing today, studies show that video conferencing allows for qualitative data collection and estimates future trends [18].

A study on videoconferencing systems showed that they provide learning opportunities and challenges to both instructors and students [17]. With the emergence of videoconferencing, the physical separation among members of a team is rendered insignificant. Its capability to meet face-to-face makes it an integral part of online teaching, research, and learning experience. Most video conferencing applications adapt to network volatility such as impairment due to congestion, end to end delays, and high bandwidth requirements. The video conferencing applications adapt by either increasing or reducing their traffic data, sending scalable codecs, and using redundancy to prevent packet losses, amongst others, to maintain a minimum Quality of Service (QoS) [19].

Other popular technologies for collaboration that also enables remote research are Virtual Network Computing (VNC) and Remote Desktop Protocol (RDP), which are login services to a remote desktop from any location. They have their varieties [9] [10] with VNC being straightforward, open-source, and robust technology-based on Remote Frame Buffer (RFB) protocol while pressing security issues within Microsoft's RDP takes precedence. The advantages of online research, such as reaching out to people at distant locations and automated data collection, reducing the researcher's time and effort, and disadvantages of being uncertain of data validity [11], were enumerated [12] decades ago when internet technology was still evolving.

The benefits of online research are openness, increased geographical scope, and more extensive representation. The difficulty in discussing and explaining complex issues and trade-offs between cost savings and cost incurred in managing and maintaining the online infrastructure [13] are some disadvantages. According to Zimitat and Crebert [14], the term "research" also covers evaluations of teaching and teaching practices. Online education has become very popular since it suits populations who do not prefer to attend regular universities/schools due to personal or other compelling circumstances. The advantages will support the current Department of Education initiative of greater access to STEM studies.

Presenting BMC development through videoconferencing has many challenges in contrast to traditional computing due to the uniqueness of BMC. Using a simple presentation, Fig. 1 introduces BMC to undergraduates, quickly showing them the essential facts of BMC and its differences between BMC and OS-based computing systems. The figure shows the hardware's transparency to an application programmer and the abstract middleware layers to access hardware. The figure describes how the application programmer is also a systems programmer. It also illustrates the major disadvantage with OS vulnerabilities showing the level of control the BMC application/system programmer has over the application; therefore, it illustrates to the student what they must learn to successfully produce a bare application.

Since the beginning, BMC research took place in the laboratory environment until lockdowns were imposed due to the pandemic and needed to continue with remote research. This paper highlights the challenges faced while moving BMC research online and is organized as follows: Section II describes the BMC potential for undergraduate work, Section III describes the BMC Development Environment, Section IV focusses on the Online BMC Research and Development Process, Section V talks about our findings on the Advantages, and Disadvantages, Section VI discusses the accomplishments of the Remote Research, and Section VII brings out further research and Conclusion.

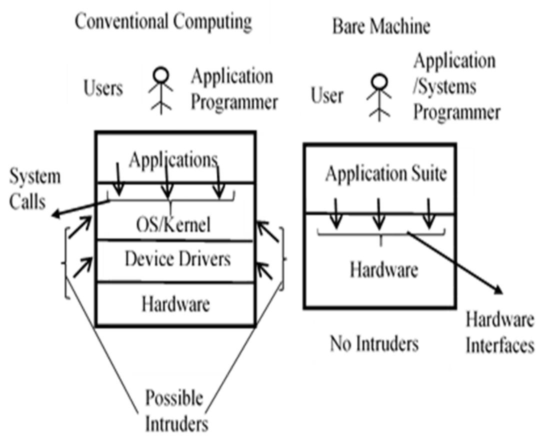

Fig. 1 Conventional / BMC Computing

II. DEPARTMENT OF EDUCATION: BMC POTENTIAL AND ACCESSIBILITY FOR STEM UNDERGRADUATES

The current agenda of the Department of Education (DOE) desires to prepare students at all levels to solve problems, collate information, and perform proper research. Fluency in science, technology, engineering, and math education or STEM will accomplish this. The DOE published a plan in 2018 for the next five years, where all students will have access to high-quality STEM education, with the United States being a leader in STEM literacy. BMC research lends very nicely to STEM within the undergraduate programs in Computer Science, Information Technology, and Computer Information Systems. BMC transition to remote research will fulfill the goal of all students to have access to high-quality education. The first question is, how will BMC Research create fluency in STEM undergraduates?

The process of transforming an application to execute on a Bare Machine requires the following steps. First, the researcher must deconstruct the binary executable. Then identify the external calls and calculate the entry point for the BMC loader. Afterward, map and create an executable table of external calls. Then, prepare the loader to load both this table and the binary executable into memory. Finally, replace the external calls with the new calls developed for the Bare Machine.

Most BMC researchers teach undergraduate Computer Science, Information Technology, and Computer Information Systems courses as graduate assistants or adjunct faculty before and after graduation. The research experience and discoveries are useful to illustrate to undergraduate student arcane and theoretical concepts. Taking the undergraduate through these steps by transforming a simple binary executable to run on a bare machine or bare internet protocol in relevant classes will enrich computer science students with relevant STEM concepts. Further automation and graphical presentation will further endow the computer science STEM disciplines. The following suggests where BMC research and its results can improve STEM education for undergraduate information system majors.

1) Computer Science

BMC research helps a prospective student delve into programming languages, including source code and binary executables. The BMC aims not to create a product that will do away with an Operating System, but research and a return to Computer Science basics.

2) Low-Level Programming Languages

Research has created executables that run an application on a bare machine. One approach was to re-engineer an application that makes it compatible with a bare machine using C/C++ and Assembler. When re-engineering an application, the researcher must write compatible bare external system calls. When an application runs under an OS, the external system-calls invoke and schedule interfaces with memory and devices. In BMC source transformation, the researcher must develop and organize APIs by the BMC load program as it loads the bare application. An Undergraduate student working in BMC research will become adept in the C/C++ programming language as well as Assembler. Even if they delve into other Computer Science disciplines, BMC will prepare the student in understanding operating systems for any device.

3) Hardware Engineering

Using the above example, when transforming software for a bare machine, the researcher must develop device drivers. OS compatible APIs that interface with the devices are not transportable to the bare machine boot loader. In that case, as the researcher transforms applications, the researcher must reuse APIs already developed or perform research of the transformed executable, identify the requirements of the API, and develop a new reusable API for BMC. This exercise will introduce the Undergraduate to electrical engineering concepts, peripheral device engineering, and network engineering, particularly routers or servers.

4) Software Engineering

To make BMC work, we described an architecture to make the process work, and we described the environment to support researchers in remote locations. The BMC newest transformation method [3] [7] involves the binary executable, hence binary transformation. In this, the bootloader receives the length and entry point parameters, a total number of system calls, which bring the binary executable into the bare Machine's memory. Much of the research is manual, and the development is manual. However, creating an infrastructure where the transformation will become automated will be the study's natural result.

BMC research is pure research, and it was not the intention to create a product. Nevertheless, in an undergraduate STEM setting, this will occur after time. BMC will generate a new design lifecycle with new milestones and methods of reporting. Also, there will be new methodologies for configuration management.

5) BMC Undergraduate Remote Research

Remote work was a business concept to leverage workers who could not reside in the business location but were critical to its operation. This paradigm expanded due to compounding internet technology and tools. Then with the onset of the COVID-19 pandemic, remote work from home and online business became mandatory for critical businesses to exist and became a new normal.

Educational Institutions had to quickly adapt to a 100% online environment to support thousands of students ordered to return home in continuing their studies. Suddenly group projects, collaboration, and lab work were now remote. Undergraduate research can happen year-round. Workshops and seminars emphasizing a discrete discipline, like Bare Drivers, Bare Network, or even Bare VOIP, can be offered.

III. BMC DEVELOPMENT ENVIRONMENT

Accomplishing BMC research using remote development faces challenges. The main challenge of BMC development relates to its novelty, and therefore limited development and debugging tools. Traditional software development tools are based on an Operating System and do not run on bare machines. Also, BMC applications used dedicated device drivers with their application suite. They do not run on current VM (Virtual Machine) environments, and application suites are written in a single programming language environment using C/C++. Some small parts of the code require low-level assembly code. Researchers need a thorough understanding of the following skills: a.) internals of a multicore architecture [20-21], b.) interrupt mechanisms [22-23], c.) NASM/MASM assembly code, d.) QEMU [26], e.) existing Bare Machine device drivers (Ethernet), f.) Bare Machine file transfer protocols, g.) Bare Machine Global Descriptor Table (GDT), h.) Bare Machine Interrupt Descriptor Table (IDT), i.) in-depth knowledge of Intel architecture [27], j.) real mode, k.) protected mode, l.) 32 and 64-bit mode intricacies, m.) the stack, n.) parameter passing, o.) Task Segment State(TSS), and understanding of BMC principles gained in prior research. Researchers leverage these skills when teaching STEM undergraduate.

Mandatory lockdowns and closures created an opportunity to modify BMC application development to an existing Web server application that could run on Intel Multi-core architecture, described in Fig.2. The development platform for BMC includes a bare machine where an application runs and a Windows machine dedicated to software development with Visual Studio compilers creating executables without using any of their default system libraries. Currently, the BMC development environment is not accessible through the Web due to a lack of commercial tools in the BMC paradigm. While working remotely, the research team consisted of two faculty members and three doctoral students. Each member of this group had a diverse skill set, and it was essential to work together and remain cohesive to accomplish the research goal. The researchers are now using these discoveries to teach network protocols to undergraduate students. The following paragraph discusses the high-level points of the development tasks.

A. High-Level Description of Tasks:

Two faculty advisors are leading the research on the bare machine paradigm. One faculty is a systems programmer, and another one with network and security expertise. One student had in-depth knowledge in multicore, another one is an expert in low-level programming, and the third one had some skills in systems programming. It was required to develop a variety of skill sets and knowledge to cooperate and communicate between the group members and posed many daunting challenges to work on the Webserver application with new design objectives. The research and development concentrated on reusing some of the components of the Webserver code from previous designs. This code needed to be modified to make it work with the new design requirements. Some significant components consisted of boot code, loader, task creator, device driver, interrupt, application code, direct hardware interfaces, network protocols, and concurrency control mechanisms.

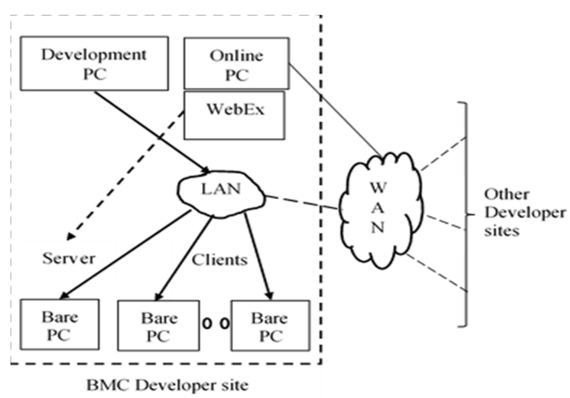

Fig. 2 BMC Development Environment

IV. Online BMC Research and Development Process

The research and development process in BMC is unique and different from other conventional systems because the application programmer must learn how the application will interface with each direct device interface with the device replacing each system call. Dispensing this knowledge to the undergraduate STEM student would improve STEM literacy in the Computer Science field. For example, BMC allows an application/system programmer to read an Ethernet packet arriving in the network interface card (NIC) and increments the receiving buffer pointer, and directs and processes it at Ethernet, IP, and UDP/TCP levels as a single thread of execution in the application program. A single thread of execution implies that it runs without swapping a running task.

There are no privilege levels in the BMC paradigm, unlike the OS domain, where it would be mandatory to prevent the users from interfering with the OS or kernel. Executing the application without the abstraction of the OS allows the student to see the intricacies that are usually hidden behind OS abstraction and only described by a dry textual narrative. Now the student observes it as it happens.

Applications running on a bare machine are event-driven. Thus, all interrupts are also visible to the BMC programmer. With the addition of execution logs, the BMC programmer can see the registers' results and heaps as the system sees them. The instructor who does this research can show the undergraduate student these activities. This visualizing of arcane concepts will improve understanding of the undergraduate STEM student.

The above development process illustrates the complexities of the research and development of BMC applications. When this process takes place remotely, it is evident that it poses different developers' design issues other than a conventional remote development process. However, when presented in-person or online to remote students, these intricacies illustrate a visual representation of software to architecture that improves the undergraduate's learning experience.

V. Advantages, Disadvantages of the online environment

The online research and development and work from home [24] have been in a push for an extended time. While not all working environments utilize remote, software-related work, they have been online for a considerable amount of time and reality [25]. Even AGILE teams requiring local face-to-face project teams [28] do remote operation even during normalcy. As long as the team can develop, test, and deploy, there is no longer a need for physical face to face meetings/work/research.

Remote BMC research resulted in the following advantages and disadvantages.

A. Advantages

a) Time: Saved the traveling time to and fro from the campus on all workdays, including preparation, travel, and traffic.

b) Flexibility: There is more flexibility to working hours, including weekends.

c) Cost savings: There were considerable savings in many items, including but not limited to travel-related expenditure, including fuel and parking fees.

d) Learning and Future Preparedness: Motivating students to learn and experiment with different online tools and the ability to be prepared for situations of a similar kind. Including social and community-related work.

e) Global Market skills: Provided skills needed in current globalization trends and market

f) Team Work: Researchers often worked independently in the laboratory environment, but these same teams were more prone to exhibit greater cooperation, teamwork, delegation, and work distribution within the online environment. Everyone had to contribute, resulting in open discussions and knowledge sharing between the research team members, eventually leading to a productive collaborative work environment.

g) Savings to the employer: Allowing remote work saves employers resources such as building space, offices, classrooms, utilities, and maintenance. For economic reasons, it may be possible in the future to entirely create virtual campuses.

h) BMC Specific: The online trend gave a new dimension to the BMC paradigm. BMC application development also needs online tools and techniques that are already available for conventional OS based application development. As there are no multimedia tools available at present in BMC development, it also opened the thinking on connecting the bare Machine to the new tools, which added to the scope and extension of BMC research.

i) Student accessibility: Students may no longer be restricted from innovative STEM programs simply because they cannot relocate to the area where the program resides commensurate with the DOE accessibility goals.

B. Disadvantages

a) Hardware and Tools: Technology services must provide each research team member with their own set of hardware and local environment since it was no longer possible to share these tools in the laboratory. Special permissions were needed from the campus to take the hardware home. Upgrades and maintenance for the windows development boxes were a significant issue. Technology services also customized each BMC development box for development and designed to be local from the campus machines. Initially, the work ran slowly due to the online tools' learning curve and adjustment. The BMC development also requires downloading many online tools that are not common to conventional OS based development systems.

b) Assignment/Meeting Schedules: Matching researchers with specific assignments are problematic. BMC is specialized, and many software components require specialized knowledge and skill set. For example, modifying an assembler module whose function interrupts an external device requires thorough knowledge of the device and assembly language. With graduation and schedules, there may be only one researcher with this expertise available. When integrating a device driver into BMC, a systems engineer must help integrate the interrupt handler. These situations presented challenges in creating a schedule to coordinate researchers with specific tasks impeding the research and development process.

c) Network Issues: The Network environment and Configuration of the group members varied as per Internet Service Providers (ISP). The development boxes were tuned to work with the local ISP providers. A prototype running in one researcher's device may or may not work the same way in another researcher's device because the IP and the MAC address configuration different for BMC compatibility. When a component was ready for testing, it was essential to test in multiple locations, resulting in increased time and effort. Each researcher had their network bandwidth issues because various ISP subscribing options and family members competing for network bandwidth, making video-sharing problematic upon occasion. The bare server and clients do not have any multimedia support, making sharing online difficult during the meetings. Sharing code through google drive, uploads, and downloads also consumed a fair amount of time, impeding the development process. It is much faster to share and resolve issues immediately when in the laboratory.

d) Component Testing: Due to the absence of software testing tools in BMC, assessing the impact of a specific component change on other components or parts of the program required all members to be present sometimes. Because of schedule conflicts, some team members had to wear multiple hats. Such a situation is less likely in a laboratory environment where people are physically present as per their schedules.

e) Online Conversations: As the group members have diverse skill sets, online conversations also result in miscommunication. It is easier to explain things when members are physically present in the same place, rather than online.

f) Management Appreciation: Working or carrying out research from home could sometimes obscure people from the management as their efforts and time spent is not directly visible to befit appropriate rewards. There are no comprehensive metrics to evaluate online work in a university setting's research and development environment.

g) Leverage of time: Productivity may suffer from at-home distractions like family interruptions, social texting, social networks, and other personal entertainments.

h) Lack of Cohesion: People generally require personal and social contacts with other people to learn, associate, and improve morale. Remote work can hinder creative synergy and hence lacks cohesion and a sense of team.

i) Research Focus: Research requires intense focus on problem-solving and creating new ideas. Productive research can only happen when a person can focus for long periods. The research environment plays a significant role in helping a student stay focused and connected to the problem he/she is researching. The home environment is for living, not research, thus impeding the focus of the researcher.

VI. Results of Remote Research

Even though BMC research was remote for the first time, there was considerable research advances over this period. The first task was to convert the boot and startup code of web server multicore architecture from TASM/MASM assembly to NASM assembly code for better compatibility with the assemblers available today. Researchers removed redundant code and streamlined the web server and web client. The keyboard and timer interrupt in both the entry startup code and the application now utilized shared memory. The startup code now includes every core in a multicore architecture, quickly demonstrating to the Computer Science students how each core in a multicore architecture starts. Students can also watch the system's transition from 16 bit to 32 bit and then to 64-bit modes.

VII. Further Research and Conclusion

Bare Machine computing has opened up new avenues in research over time. One such research line uses the tools built for BMC to introduce STEM undergraduates to fundamental principles of Computer Science and Computer Engineering. As brought in Section V1, not only were discoveries made, but new applications of those discoveries were relevant to enhancing STEM education. As this research continues, the BMC research team members need to pursue the following items in later research.

a) Research to enhance live code collaboration tools applicable to in-person and remote BMC developers/researchers [28]. Students doing remote research/collaboration must be up to date on the current tools and techniques that requires an additional learning curve as tools continue to change/emerge.
b) Further research to make the BMC paradigm available online with multimedia, collaboration tools, and educational techniques to relay to new STEM undergraduates.
c) Further research on the binary transformation of existing device drivers is needed to support the fast obsolescence in internet technology to support sustained global computing and infrastructures.
d) Research new ways to automate simulations of Bare Machine applications and Bare Network operations for STEM undergraduate education.
e) Research how to build Bare Machine simulators for learning aids in undergraduate System Architecture and Operating System classes.
f) Research on social and psychological needs arising from remote research to address isolation, distraction, ethical protocols, special needs of undergraduates, and basic training for tools specifically developed for remote learning.
g) Students doing remote research can have priorities shift due to different teacher's and advisors' conflicting interests and requirements. Therefore, BMC research should partner with graduate education offices to find tools and procedures to maintain accountability and focus on remote research and education.

As BMC continues its research and adds more bare applications, it will adapt these milestones to improve undergraduate students' STEM education. The dynamics of education or the new normal are not yet defined. However, there will still be issues posing significant challenges to information technology to deal with emerging online teaching and learning trends. BMC research will be part of this.

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