The CCL-Parallax Programmable Badge: Learning with Low-Cost, Communicative Wearable Computers

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ABSTRACT
The rise of "Bring Your Own Device" programs, the emergence of wearables and interactive electronics, and the growing presence of the "Internet of Things" in the workplace, all present new challenges to members of the IT profession. To prepare students for this ever-changing landscape, we propose the use of low-cost, wearable badges to introduce learners to central IT concepts in an innovative, engaging, and social way. In this paper, we introduce the CCL-Parallax Programmable Badge – an open-hardware communicative device that uniquely brings together various components of the IT curriculum. Along with introducing the badges and situating them within almost two decades of research on the use of similar devices in educational contexts, we present both theoretical and practical justifications for the use of programmable badges in IT classrooms. The badges highlight the collaborative, social aspects of IT while grounding the learning experience in authentic, motivating, and hands-on activities.

Categories and Subject Descriptors
K.3.2 [**Computers and Education**]: Computer and Information Science Education; Computer Science Education

General Terms
Design, Human Factors

Keywords
IT Education; Open Hardware; Programmable Badges; Participatory Simulations; Networking and Communications

1. INTRODUCTION
As the demands on IT professionals shift in response to emerging technologies and trends in the workplace, so too must IT education programs evolve. The rise of "Bring Your Own Device" programs, the emergence of wearables and interactive electronics, and the growing presence of the "Internet of Things" in the workplace, all present new challenges to the IT profession. These changes should be met with innovative approaches to IT education. In particular, there are emerging opportunities to integrate the ubiquitous, communicative computing devices that make up the Internet of Things in learners' early exposure to the principles of IT. In this paper, we argue that open, programmable interactive electronic badges can serve as an engaging and effective way to introduce central IT concepts and practices. We present a new platform in this category, designed in partnership between the Center for Connected Learning and Computer-based Modeling (CCL) and Parallax, Inc. These electronic badges are inexpensive, programmable, wearable devices that communicate via infrared signaling. They feature 100% open-source hardware and firmware, and they come with all the necessary components to interface with computers and communicate with other badges.

The badges, and the activities designed around them, can be a setting for exploring numerous aspects of the IT field including programming fundamentals, HCI, networking, and integrative programming. Moreover, activities with the badges can raise thought-provoking questions around information assurance and security and can foreground practical and ethical aspects of data management. Further, badges reflect the broadening scope of the IT profession, making social interactions central and highlighting the larger shift of technology away from workstations and screens, and towards a growing class of distributed networked computing devices. Finally, because the entire platform is open source, "hackable," and extensible, IT learners have no sharp end to their explorations with the badge and can move seamlessly into neighboring areas such as electronics design and mechatronics. This paper provides a theoretical and practical motivation for bringing badges into IT classrooms and presents the technologies used to realize this approach for teaching IT.

2. INTRODUCING ELETRONIC BADGES
The CCL-Parallax programmable badge is based on the Propeller 8-core P8X32A-Q44 microcontroller used in the flagship Parallax platforms, including the Activity Board. Options for Integrated Development Environments (IDEs) and programming languages include the full range of Parallax's offerings. This includes the Simple IDE (SIDE) and the BASIC, C, Spin, ASM languages, as

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well as new offerings emerging from the vibrant Parallax user and developer community. The multicore design also enables concurrent control of the visual display, 3-axis accelerometer, pushbuttons and LEDs without creating monolithic, looping programs. The badges are 100% open, and the Propeller Multicore itself is released under the GPL 3.0 license.

The badges are amply equipped with hardware capabilities chosen specifically to fuel the imagination of learners, including:

- Two-way Infrared communications (i.e., LED and Receiver)
- 128x96 OLED display
- Stereo audio and composite video out
- 3-axis orientation & motion detection sensor
- 2 programmable tricolor LEDs
- 6 passive touch pads with one-color indicator LEDs
- Rechargeable battery
- USB connectivity, for connection to host to program RAM and EEPROM, and to recharge battery.

This set of on-board capabilities supports a wide variety of activities. At the end of the paper we present a pair of sample introductory activities demonstrating how the badge can be integrated into IT classrooms in a "low threshold" way. Moreover, the badges encourage hardware and firmware expansion, along with software programmability; thus, they have a very "high ceiling" and can be used for advanced applications as well.

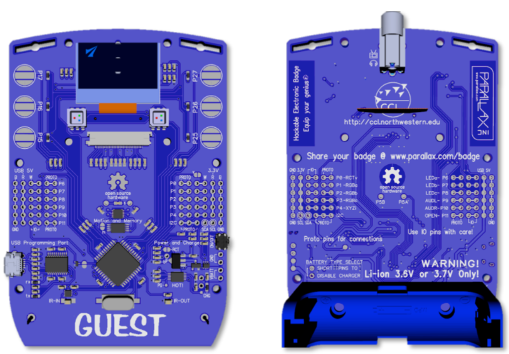

Figure 1. Prototype designs for the communications badges

3. BACKGROUND LITERATURE

In this section, we review the literature on electronic badges, showing how the CCL-Parallax platform is positioned to unify several divergent themes that have appeared over the history of research on this genre of wearable computing devices. Later, we build on these ideas to reinvigorate and unify several promising threads of research using new technologies and innovative implementations.

3.1 Badges for Efficiency

Electronic badges arose over 20 years ago with explorations of portable interactive computing objects (PiCOs) and a desire to provide real computing power in such devices [25]. Active Tags, the first PiCOs broadly used, were seen originally in terms of efficiency and security in companies, typically used to track location of users or act as electronic keys for workstations, rooms, or telephones. As the technology advanced, designers explored further applications in office management such as tracking employees' locations based on their relation to workstations or other badges [24]. These systems were later expanded for location awareness in more mobile communities, like motorcycle groups [11]. A common theme through this early history is the metaphor of the badge as tag: a label used to identify and classify its wearer.

3.2 Badges for Social Interaction

Early versions of communicative electronic badges typically supported *asymmetric* interactions and communications in which human wearers played a *passive* role, (e.g., as tracking devices or keys), with location information emerging as the "trace" of these interactions. A next step was to investigate their capabilities for *symmetric* interactions in support of *active* interpersonal communications. Here badge-to-badge communications served to augment human-human interactions. Working to explore badges' utility in facilitating relationships between people, Borovoy and colleagues developed Thinking Tags [4]. Here the metaphor of badge-as-label was expanded to the metaphor of badge-as-nametag. Thinking Tags and, later, Group Wear badges were used at conferences and other events and went beyond traditional nametag content. For example, users could "program" their badges at kiosks by dunking their badges into electronically instrumented "buckets," each corresponding to different responses to multiple-choice questions [2]. During face-to-face interactions, the badges then would exchange information and flash a pattern of LEDs, reflecting the commonality in their wearers' responses, supporting and even stimulating meaningful social interactions.

The MIT Meme Tag advanced this trend further, by making tags more easily programmable and by aggregating, analyzing, and displaying social media data (e.g. "top schmoozers") in public displays that acted as "community mirrors" [3]. These advances also reflected another metaphor: that of the badge as mask, costume, or role-identifier. Meme Tag activities showed that badges could be used socially with the technology facilitating role-playing activities.

In parallel, other badge designs explored and advanced the theme of individual expressivity. Similar to the Meme Tag, designers of the BubbleBadge developed a badge in the form of a brooch that provided users the ability to display continuously changing text messages [12]. Here, yet another metaphor emerged: the badge as an adornment, a way to express one's style and personality.

3.3 Badges for Education

In educational spheres, researchers were exploring how these technologies could be used to provide learners with engaging and authentic educational experiences involving science, computation, and programming. In particular, researchers saw opportunities to build on Seymour Papert's vision of computing, in which learners explore and construct their own understanding using technology [19] along two strands: (1) by engaging in social interactions, and (2) by leveraging physical constructions. Relying on the pedagogical power of social interactions, educational researchers began investigating ways to blend explorations of multi-agent computational systems with socially-shared embodied activities. In the late 80s and early 90s, Wilensky & Resnick began building on Papert's ideas and the Logo tradition in computer-supported learning. They created a massively parallel Logo with *many* turtles. This paradigm was useful for modeling multi-agent systems and complexity, and it also suggested embodied activities in which researchers built on the Logo tradition to "play turtle," now allowing *groups* of people to engage in this form of activity. These "StarPeople" activities were deployed at conferences and in educational settings in the mid-90s, where participants typically played the role of systems agents, moving around the room and exchanging "messages" [22, 23, 27]. Participants then could witness the emergence of global patterns arising from their local interactions, as individual-level actions were aggregated and analyzed to provide illuminating representations of the simulated system as a whole. This work paved the way for a class of activity called Participatory Simulations ("PartSims"), developed and researched extensively by Wilensky & Stroup [29]. Thus, PartSims that involved participants in physical role-play both pre-dated and interacted with research using badges. Wilensky's creation of NetLogo [26] then enabled both researchers and learners to model multi-agent complex systems using personal computers, and the HubNet module [29] connected this modeling environment to distributed computing [30]. Moreover, HubNet could be used with a variety of clients, allowing different blends of physical and virtual activity, including Texas Instruments graphing calculators equipped with motion sensors [31] and cell phones incorporating real-time GPS data [28].

Meanwhile, Colella and colleagues engaged in PartSims research focused centrally on badges [9]. Their work in simulating disease spread found that high school students drew heavily on personal experiences, knowledge, attitudes, and interests during PartSims [8]. These findings were mirrored in other studies with thinking tags [1] [17]. In spite of these successes, badge-based PartSims were largely set aside in the mid 2000s. On one hand, personal digital assistants (PDAs) caught many researchers' attention as PartSim platforms [15]. On the other, much of the focus on programmable devices turned toward robotics, as the technology in thinking tags was placed in the programmable "bricks" that had shown promise in engaging learners and teaching programming.

In exploring the power of physical constructions, programmable "bricks" were originally designed to act as autonomous "creatures" that learners could program [10, 18]. This approach emphasized the design of construction kits over ready-made objects [21]. These bricks were found effective for teaching robotics and programming. Later, they were redesigned as smaller tools, called Crickets, which had communicative capabilities similar to thinking tags. Multiple versions were designed that afforded varying emphases, including social interactions, science explorations, or personal modifications [18]. Learners explored personal interests by programming, constructing, and modifying their Crickets to perform desired tasks. In the Beyond Black Boxes (BBB) project, the MIT Media lab converged on a Cricket design that emphasized scientific applications and provided an entry point into authentic scientific practices [18, 20]. Moreover, these tools were not only leveraged for authentic exploration of scientific concepts; learners also used prior experiences, interests, and motivation to fuse science and engineering with other content areas, like art or music [18]. These tools remain a successful pathway into computation and scientific practices, as can be seen with the recent resurgence in physical computing through platforms like Arduino, GoGo Boards, pcDuino, and LEGO Mindstorms. The landscape of physical computing is rapidly expanding, and we argue that badges have a role in fueling this growth. Badge technology has advanced sufficiently to support not only participatory simulations but also science exploration, robotics, and programming education. Thus, multiple strands of work can be brought back together to engage learners across a wide range of fields. This speaks to the opportunity at hand to reimagine and expand on what IT education can be.

4. WHY USE ELECTRONIC BADGES?

The expertise required to be a successful IT professional is quickly shifting, from a narrow skillset based on knowledge of a few industry-standard platforms towards a diverse and ever-changing collection of skills and approaches. In order to prepare learners for this unpredictable landscape, IT educators similarly must adapt and innovate, incorporating new technologies and pedagogical approaches into their classrooms. Central to the design of IT educational programs is the choice of technology to ground students learning experiences. Given the radical shifts in the profession, it is important to use tools and platforms that support a diverse set of motivating activities that reflect the changing face of IT. In this section we argue that electronic badges provide an authentic and inviting, yet powerful, context for both introductory and more advanced IT instruction.

4.1 An Innovative and Engaging Approach

Numerous aspects of the CCL-Parallax programmable badge make it a compelling context for teaching foundational IT concepts. Programming hardware is motivating, and the built-in hardware of the badge supports a variety of explorations out of the box. Students can see physical effects in their badges with their earliest software experiments – blinking LEDs, programming the OLED display, and detecting changes in sensors such as the onboard accelerometer. The open hardware design creates a "glass box" environment, where students can directly map software logic to hardware outcomes. This is in contrast to conventional computers, which are extremely complex machines that are not easily understood due to their massive resources, high speed, and closed architecture, ultimately black-boxing much of the computation that is happening. Transparency can be both pedagogically and cognitively powerful, giving the learner access to and control over parts of the learning process often hidden from view [20]. Through the use of physical computing, it is possible to make introductory activities rewarding for the learner, while also laying a foundation for investigating more sophisticated concepts later in the course.

The badges also introduce engaging social and aesthetic dimensions to introductory IT education. Being wearable, programmable, and customizable, they can support tightly structured activities where learners employ specific IT concepts, but they can also be personalized, decorated, and integrated with a range of other technologies. Providing learners with opportunities to engage with IT ideas in contexts beyond conventional computing settings can broaden the range of activities used in class and help to appeal to a wider and more diverse set of students. For example, integrating badges with e-textile technologies can build on existing approaches to computer science education that have been found to successfully engage female students that are historically underrepresented in the field [5, 6].

The engagement made possible through the use of programmable badges is not only an intrinsic characteristic of the devices themselves. The badges also tap into the excitement surrounding the "Internet of Things" and the Maker movement. The CCL-Parallax programmable badges blend features of both of these communities, being networked and wearable, while also being an inexpensive, open, and "hackable" platform. Like other tools such as the Arduino, pcDuino, Beagle Board, and GoGo Board, the CCL-Parallax programmable badge aligns itself with the larger Maker movement, which has lowered barriers to participating in the design of electronics and interactive "smart" objects. We have already seen examples of how such low cost hardware tools can successfully be integrated into IT education [13]. Further, with a generation of people growing up building and tinkering with electronics, it stands to reason that IT professionals will be expected to be able to accommodate colleagues who want to integrate such tools into their professional lives.

With the introduction of the Apple Watch, and other technologies like FitBit, it seems the long-awaited age of wearables has finally arrived. To date, much wearable technology has focused on the personal and social aspects of people's lives, but we expect that wearables will also soon be an integral part of the business world. Badges can serve as an accessible and inexpensive entry point into this space. Thinking through how to support such interactions, both in terms of the devices doing the communicating, and the systems that will support them, is a challenge IT professionals will face in the near future.

4.2 Making IT Social

The field of IT, like computer science more broadly, suffers from the perception that its adherents are signing on for a professional life of solitude. This could not be further from the truth, as working with colleagues, both in the IT field and beyond, is essential to succeed. A recognition of this fact is reflected in the inclusion of social dimensions of the field in recent IT curricular guidelines [16]. Building IT educational activities around programmable badges helps to highlight the social side of IT. While learners can develop and implement badge programs independently, they cannot test or deploy them fully on their own. Activities based on inter-badge communication involve solutions that can only succeed when students collaboratively develop the protocols together. And just as badges can make IT social in the classroom, so too can they bring IT concepts into social settings outside the classroom. Early work with communicating badges supported interactions at social functions; having a class build a set of communicating badges provides a natural way to share what it means to be an IT student in settings beyond the classroom, be it at social function within the department or beyond.

Programmable badges have already been found to motivate social interaction and collaboration at events within the IT industry. Predecessors to the CCL-Parallax programmable badges have been distributed to attendees of DEFCON conventions[1] where they were used, for example, in conference-wide cryptography challenges. There, in order for participants to make progress in solving cryptographic puzzles, they had to interact and swap information with other badge-wearers, showing how badges can drive social interactions. The activity fostered peer-to-peer collaborations and increased the number of "shared interest" contacts; it has since become one of the more popular annual features of the event. The extensibility and capabilities of the DEFCON badges are also on full display at the conference as some users have turned their badges into quadcopter flight controllers or built complete computers – all run through the badges hanging around their necks.

4.3 Providing an Authentic Learning Context

As students design and deploy badge projects, they face similar issues and challenges to those encountered in the context of real-world distributed computing applications. Students work towards outcomes they themselves have conceived of and are invested in. The physicality of the activity plays an important role in engaging learners, since the data they gather—and the bugs they encounter—come directly from interactions with their classmates and their classmates' badges. The use of real, physical devices, as opposed to computational simulations of devices, has been found to positively affect student motivation, engagement, and learning outcomes [7, 14].

Badges also provide authentic experiences of the social aspects of the IT field. First, students must work together to define communication protocols, or their badges will not successfully exchange information as required. Second, to verify that a badge is working as expected, students must engage with classmates. Because students are using their own badges, they become their own clients, deciding for themselves if the application fulfills their requirements. Finally, students are also dependent on the behavior of other students' badges, meaning they are also the clients for other students' projects. This gives them the experience of giving and receiving feedback, as well as managing incoming feature requests and bug reports.

4.4 Badges across the IT Curriculum

Our final motivation for using badges in introductory IT contexts is their ability to effectively introduce learners to diverse aspects of the IT field. In 2008, a joint ACM/IEEE committee published a comprehensive curriculum for modern IT educational programs [16]. The curriculum describes the diverse skills that collectively comprise what it means to be an IT professional. Given that electronic badges are situated at the intersection of hardware, software, and social computing, they provide a context for activities that engage with many of the key issues, principles and practices of the IT curriculum. In this section we map out portions of the curriculum that can be taught with the badges.

4.4.1 Programming

The electronic badges are communicative devices: this means they "want" to share and receive data from other badges, through behaviors that must be programmed. The most common environment for programming the Propeller chip is a variant of C, a foundational and widely-used programming language. To create a badge program that can successfully send and receive messages, numerous programming concepts must be employed. This includes defining what information the badge will share, as well as how it will respond when information is received. Defining communication behaviors for the badges requires students to integrate fundamental programming concepts including variables, conditional and iterative logic, defining and using functions, defining and implementing algorithms, and dealing with various computational abstractions. As badges may receive multiple messages during their lifetime, students must use and manage flexible data structures and will encounter various issues of data collection, management, and storage in their projects. Additionally, since the badge communication is asynchronous and can be initiated at any time, the badges introduce learners to the important paradigm of event-driven programming. The multicore processor of the CCL-Parallax badge also allows learners to engage with the challenge of parallel programming to enable it simultaneously to send, receive, process, and display data. Finally, in some applications, badges can act as just one computational element in a broader ecosystem of computation, including other badges, workstation computers, websites, and databases. Developing and deploying such distributed systems engages learners in challenges spanning many computing platforms, each with its own set of affordances and constraints.

4.4.2 Human-Computer Interaction

Understanding technology use and usability are critical skills for modern IT professionals. Electronic badges provide a context for learners to engage with central concepts of HCI due to the fact that, at various points when working with the badges, learners will be both designers and consumers of the technology. Challenges relating to HCI are encountered both in how learners envision the badges being used, and in how they plan to share the data the badges collect. The physical nature of the badges allows learners

[1] DEFCON is the largest annual hacker convention and brings together thousands of IT professionals, security researchers and others interested in cutting edge technology.

to grapple with contemporary HCI issues related to wearable and embedded technologies (e.g., Where and how are badges going to be worn? Should they respond differently when held in different orientations, as detected by the accelerometer?), as well as placing design constraints on them via the capabilities of the badges. In confronting these design challenges, learners are given the opportunity to implement and evaluate different solutions, engaging in discussions with peers about such issues as accessibility, shared interface conventions, protocols and protocol versioning, and end-user experiences.

4.4.3 Networking and System Integration

Despite the badges' being quite distinct from conventional networked devices (i.e. laptops and servers), badge-to-badge communication can be modeled using industry-standard network layer analysis. Advanced designs for inter-badge communication can involve students in defining and managing various aspects of network protocols, including work at the session, presentation, and application OSI layers (e.g., digital-to-analog and analog-to-digital signal conversion, session initiation and termination, handshaking, and user-defined application-level protocols). Also, the communications logic of the badges provides a high-level abstraction of the networking states that devices cycle through during communication (i.e. initial contact, hand-shakes, authentication, information passing, and termination). Finally, it is also possible to design activities that have the badges mimic various types of network hardware, serving roles that could model those of routers or switches in a larger network of badges.

4.4.4 Information Assurance, Management, Security

While there are other aspects of the IT curriculum that can be addressed using the electronic badges, the last we want to highlight here is how the badges introduce learners to critical issues of information assurance, management, and security. Since the badges collect data but do not come with a pre-configured data format or a system for storing or managing data, students early on confront questions of deciding what data to store and how to store it. This raises numerous operational issues related to getting data from the badges to computers for long-term storage; determining how they want to use the data they collect; and matching those uses with data collection strategies. Additionally, as students make these decisions, they encounter questions of information assurance, security, and potential ethical issues related to data collection. As with the other topics we have outlined, instructors have a range of choices about how to use the badges and what topics to engage students with.

5. SAMPLE BADGE ACTIVITIES

In this section we describe two introductory activities that could be used as entry points in a classroom setting that utilize the CCL-Parallax programmable badges.

5.1 Activity 1: Greetings

This activity is intended to serve as an introduction to the CCL-Parallax programmable badge. As such, it can be compared to other "first contact" activities, as, for example, when a new Arduino user learns to control the onboard LED and flash it in different patterns. To begin, the badges are loaded with a pre-built program that operates on two cores (called "cogs") of the Parallax multicore. One cog manages simple response-to-signal logic, as the badge listens continuously for an IR signal and executes a response when it encounters this pattern. The response provides a "system test,"—e.g., lighting the monochrome and tricolor LEDs in sequence and displaying a simple message on the OLED, and playing a tone on the audio-out. On another cog, outbound signaling is managed, so that the badge emits an encoded "1" signal continuously whenever one of its buttons is pressed. With this program running, students can test their badge using a handheld TV remote (relying only on the response-to-signaling logic); and they can inspect the code that produces the stock response. They can also trigger a classmate's badge by approaching it with their badge and pressing the button.

The activity has two phases. The first consists of modifying code to change the stock response, experimenting with the functionality of the onboard visual and audio outputs. This can be a fairly elaborate exploration, as both the tricolor LEDs and the OLED display have a wide variety of functionality that can be investigated. On creating a personalized response to the "1" signal, students can move about the classroom exchanging greetings. A second phase of the activity consists in developing "secret handshakes." By adding cogs to the program, students can create additional signal-response pairs that will activate only with a partner who has programmed her badge in the complementary fashion. For example, a student might program the badge to respond differently to the signal "2" and produce this signal when a second button is pressed. Thus, the badge would continue to respond as before to the "public" handshake prompted by the "1" signal, but it would respond differently to the "secret" handshake prompted by the "2" signal. This activity would allow very simple modifications to the logic structures running on the first and second cogs to create parallel logic on the third and fourth cogs, offering both a motivating experience of situation-sensitive social/physical computing and an introduction to the power of multi-core parallel programming.

5.2 Activity 2: PartSims and Beyond.

Our second introductory activity builds on the PartSim strand of design research reviewed above. Thanks to the badge's flexible programmability, it can extend this genre by engaging learners with principles of networking and distributed systems.

The activity begins with all badges programmed for a PartSim in which communications between badges are triggered by the explicit actions of the human users (e.g., pressing the same button on each badge when they are within IR range of one another) and information is passed between the badges (e.g., different text messages that are initially stored on several chosen badges are transmitted through the class via interactions). Understanding these steps and the badges' state machine governing interactions engages ideas fundamental to network programming. After the base PartSim is run, interaction data can be uploaded to a central computer that is connected to a monitor or projector, where the data is visualized. Replaying the interactions between badges, a network analysis of the diffusion of the messages can be shown.

An extension activity explores application protocols and error checking. Infrared communications are based on optical signals and therefore can be rather error prone. In the extension activity, error checking and correction logic is removed from the badge program, and the same simulation is re-run, providing evidence of ways that messages can degrade over multiple transmissions. Programming activities here can involve students in devising transmission protocols on top of the raw IR communications that include their own strategies for error detection and correction. This work can be done in small groups, which can compete to design a system with superior performance in terms of accuracy, resource usage, and speed of transmission. Creating these benchmark measures also offers an opportunity for discussing the application-specific nature of a good protocol.

6. CONCLUSION

In this article we have introduced the CCL-Parallax programmable badge as a platform to engage learners with core topics in the field of IT. We have summarized the historical roots of badges across commercial and educational settings, and we have shown how they draw together powerful strands of design research, emphasizing the increasingly social and distributed nature of computing. We have highlighted areas of fit between this platform and IT curriculum standards, and we have outlined two introductory activities for using the badges in a classroom setting. In ongoing work, we aim to develop these and other activities through iterative design research as the badges are produced and become available. We welcome the community to participate in this effort, and we are confident that the creativity of instructors and students alike will enrich our collective sense of what these badges can do to fuel innovative IT education.

7. ACKNOWLEDGMENTS

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