On Project-Based Learning through the Vertically-Integrated Projects Program

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Abstract – **Georgia Tech's Colleges of Engineering and Computing initiated the Vertically-Integrated Projects (VIP) program in January 2009. Undergraduate students that join VIP teams earn academic credit for participating in design efforts that assist faculty and graduate students with research and development issues in their technical areas. The teams are: *multidisciplinary* – drawing students from around the university; *vertically-integrated* – maintaining a mix of sophomores through PhD students each semester; and *long-term* – each undergraduate student may participate in a project for up to six semesters. We describe the Video and Image Annotation VIP (VIA-VIP) project, which provides undergraduates unique opportunities to learn and apply state-of-the-art video-mining algorithms by processing a large archive of football videos recorded from GT football games. Their results are documented. Based on their feedback we believe the VIA-VIP course is on track to meet the needs of undergraduates in areas they don't usually see in the traditional undergraduate classroom.**

Index Terms - project-based learning and education, vertically-integrated projects, video and image annotation

1. Introduction

Sustaining and accelerating the pace of innovation in engineering will require a continuous stream of graduates who understand how to integrate the processes of research, technology advancement, and application development must to enable innovation. Current approaches to the education of students are not up to this challenge: (1) undergraduates are generally not deeply exposed to any technology area; (2) master's students are often not involved in R&D of new technology; and (3) PhD students rarely see their research breakthroughs implemented and tested in applications.

The Vertically-Integrated Projects (VIP) Program at Georgia Tech [1, 2, 3] creates and supports teams of faculty, graduate students, and undergraduate students that work together on long-term, large-scale projects. The focus of each project team is on challenges in research, development, and applications that are of interest to federal funding agencies, industry, and not-for-profit organizations.

The design of the VIP program has borrowed the large, vertically-integrated team structure of the EPICS program [4]. This structure is a proven vehicle for the completion of long-term, large-scale design projects by undergraduates. The VIP program departs from EPICS, however, by adding graduate students to the teams and focusing the design projects on research and development efforts led by faculty. This research emphasis provides several advantages:

- It engages faculty in the project at a high level because the activities of the team directly support their research effort – including the generation of publications and prototypes. These projects thus maintain the long-term engagement and commitment of faculty, including the generation of research proposals to fund the project team.
- It engages doctoral students in the direct mentoring of undergraduates that are assisting them with their research and accelerates their work and enables the undergraduates to learn directly about the goals and responsibilities of graduate students. We expect that, when compared with students not enrolled in the VIP program, those in VIP will be more likely to attend graduate school.
- It expands the scope of possible projects to include any discipline in which faculty are pursuing research. Our initial effort focused on engineering and computer science, but the GT College of Science is now participating. The Computational Structural Biology VIP project was launched in fall 2010 and a physicist is participating as a co-adviser of the Brain Beats VIP team.
- It provides a platform for the integration of research and education in academia and creates a coherent community, including undergraduates, graduate students, and faculty, who work together to attain technical goals. This experiential component for the undergraduates gives them great insight into their field of study, all the way up to the research questions that are posed by faculty. It also provides long-term contact between all members of the team, thus leading to a much more collegial approach to education and the opportunity for long-term mentoring. These outcomes of VIP and VIP-like experiences have been documented with both qualitative and quantitative evaluations [2-5].

The recent exponential growth of online video and image archives has led to many emerging research and business opportunities for video indexing and retrieval [6-7].

The Video and Image Annotation (VIA) VIP project, also referred to as VIA-VIP in this paper, is designed to study VIA subjects, put together prototypes for technology illustrations, and research on emerging topics. It attracts 8 to 10 undergraduate student each semester and they are divided into sub-teams according to their technical interests.

The team has conducted various experiments, including key-frame image classification to associate visual features with notable semantic concepts, such as *end zone*, *goal post*, *crowd*, *camera view*, *yard-line*, and *key players*. Audio fingerprints, such as *announcer's voice*, *booing*, *cheering*, and *background activities*, have also been incorporated to enhance the categorization of video shots. Interdisciplinary topics, such as classification, clustering, optimization, machine learning, and image/audio processing, which are not easily taught in undergraduate courses, have been mastered by participating students. To enrich the learning experience and monitor progress, PhD students are also assigned to closely work with undergraduate students in weekly sub-team meetings. Undergraduate students are required to read state-of-the-art papers related to their topics and to discuss them to solve their individual problems. This paper demonstrates this collaborative spirit through its joint authorship by undergraduates, graduate students and faculty.

We have learned through our evaluation process [2-5] that the VIA-style project-based learning [8-11] within VIP programs is effective and yields benefits not available in conventional classroom and laboratory settings. These positive outcomes are supported by other evaluation efforts that have focused on self-directed and active learning experiences [8-9]. For example, the tightly-coupled student-professor relationship provides an out-of-classroom learning vehicle that will benefit students through their long-term, active engagement and the development of a cross-year and cross-disciplinary teaming skills [5]. Furthermore, the football-related focus offers an exciting context for the students that helps them relate theoretical work to interesting, real-world problems. We expect to continuously operate this project with returning students providing leadership roles in the welcoming and education of newcomers.

2. STUDENT PROJECTS

In the following, four VIA-VIP projects are presented by participating students in Sections 2.I-2.IV. In Table I we list the project topics and their corresponding techniques. Clearly many of the required algorithms are widely used in state-of-the-art systems and ongoing research.

The project topics are designed in a way that fits to different students' diverse background and interests. In particular, the project topic should be interesting enough to intrigue undergraduates. At the same time, the topic should contain some technical material so they can feel great achievements out of the assigned projects. In the meantime, the topic should not be too difficult for the students to pick up. Some of the techniques on the right column of Table I, such as SIFT, optical flow, and SVM, are not as easy as the others, such as Hough transform, to grasp in the short time interval given to the sub-teams to execute the project. We were happy to see that, after some struggle, the students were able to use them to benefit the specific implementation of the designed projects.

TABLE I
PROJECT TOPICS AND REQUIRED TECHNIQUES

Project Topics	Required Techniques
Audio event detection	Hidden markov models (HMMs), Expectation and maximization (EM), Hypothesis testing.
Keyframe annotation	Latent semantic indexing, Maximal-figure-of-merit (MFoM) learning, Vector quantization.
Player traking	Scale-invariant feature transform (SIFT), Kalman filter, Optical flow.
Yard-line and yard-number detection	Canny edge detection, Hough transform, Image normalization, Support vector machines (SVMs).
Camera rectification	Canny edge detection, Hough transform, Homography.

I. Audio Event Detection

The hybrid system introduced in this sub-team project consists of training speaker models and establishing similar rules for key-word modeling and background modeling. By setting variables and thresholds, the system is dynamic and adapts to several other applications, such as detecting musical instruments in music signals and detecting high-energy sounds at sporting events for quickly identifying its highlights. The system's implementation of audio event detection and speaker recognition utilizes Hidden Markov Models (HMMs) to calculate each model's scores at each observation frame in the audio signal from the video.

The data used in this experiment includes audio samples taken from Brian William's NBC Nightly News Podcasts that was labeled as either "BW" for Brian Williams' voice or "other" at each audio segment. HTK [12], a publicly available software tool kit written in C and commonly used in both industry and academia for speech recognition research, was used for training HMMs, and performing speaker recognition and audio event classification. The results were imported into MATLAB for creating a GUI (graphical user interface to demonstrate results and playback the time segments of the video. The readers are referred to [13] for technical topics in speech and speaker recognition.

This project evaluates a detection system used to tag time intervals in news and video podcasts when a lead anchor, in this case Brian Williams, is speaking. By detecting the time intervals in broadcast videos of all news-story segments introduced by the anchor, the video is automatically segmented and can be tagged for quick access to viewers. The preliminary speaker detection model resulted in an average of 92% accuracy. Future work includes speaker-change detection, speaker monitoring, discriminative and adaptive modeling techniques, and incorporating a bootstrapping detection layer.

II. Football Field Rectification

The ultimate goal of our group project is to build a system that automatically maps football footage onto an aerial view of the football field (this process is called *camera rectification* [14]) as shown in Figure 1. The output of such a system would be the original football footage warped so that field lines and players in the video footage appear in the correct location on the football field. Such a system would greatly simplify other video analysis tasks related to football. By mapping the original footage onto an idealized field, ambiguities resulting from camera motion, zoom, position, and angle of view, are removed. Having the footage positioned correctly onto the field makes tasks such as player tracking much more straightforward.

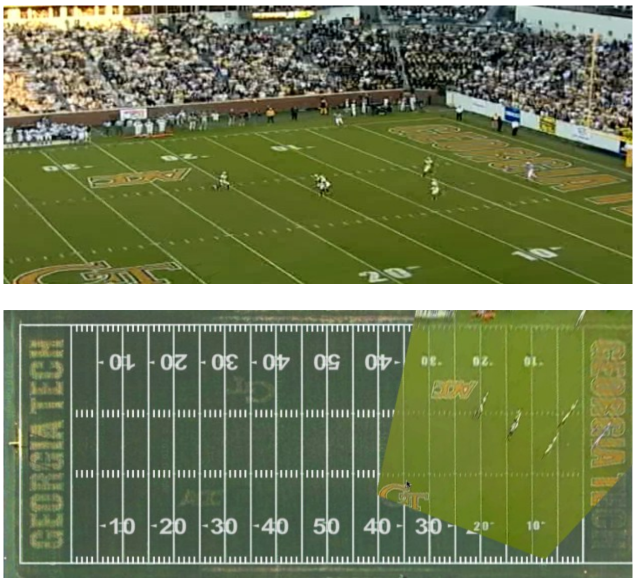

FIGURE 1
RECTIFICATION OF UPPER VIEW INTO LOWER AERIAL VIEW.

During our first semester, we experimented with and learned about a variety of techniques. Many of the basic image processing algorithms we used can be found in standard textbooks (e.g., [15]). However, our results from the first semester's work were mixed, and as we moved into our second semester (the present term) we decided to bypass the camera classification approach to confront the problem of camera rectification more directly. We have investigated and implemented a concept known as *homography* [16] that makes use of geometric relationship of sets of four point correspondences between the source and target images. This direct approach seems to work better than the indirect mapping techniques experimented earlier to map the footage image in the entire upper panel of Figure 1 to an aerial view shown as the grassy area at the northeast part with players' locations clearly displayed in the entire football field in the lower panel of Figure 1.

III. Key Frame Annotation

The goal of keyframe annotation [6] is to automatically assign labels to certain objects and/or events within a video. One application of the project that we focused on was annotating football video clips where we devised some labels that we would like to find in the videos such as "goalpost," "endzone," and "crowd." We concentrated on making a detector for each concept. This was accomplished through a multi-step process detailed as follows: keyframe extraction, low-level feature extraction, vector quantization, feature mapping, latent semantic indexing/singular value decomposition, and finally, detection. Two detectors were used, one concentrated on detecting labels using texture, while the other used color. Parameters for the detectors were determined using brute-force methods in order to achieve high precision and recall at the same time for a set of test images. We have also discussed many future enhancements to the project.

IV. Player Tracking

Player tracking is an important research and practical topic for information extraction from sports videos [17]. Most algorithms use either multiple cameras (multiview) or a single moving camera. The VIA-VIP player tracking project is intended to work with a single camera. It consists of two methodologies. The first combines three algorithms to take the initial objects (e.g., football players, referees, etc.) and track their movement through frames of a single video clip. The techniques used include *scale-invariant feature transform* (SIFT) [18], *Kalman filtering* [19], and *optical flow* [20]. They were used in conjunction with one another in a high-level algorithm to accurately pinpoint the locations of the tracked players.

The second method uses pixel matching to find the next region more directly but involves other techniques to assist in removing distracting objects. It has been used separately to provide comparative results on the relative success of techniques for our application. Simple frame-by-frame pixel matching is used within an expanded region to find the closest match. An object to be tracked is compared with similarly sized windows within the region of the next frame. The new coordinates of an object is determined by whichever window produced the least squared error.

One aspect of player and referee tracking that has yet to be addressed is the initial detection of these objects to track. Automation of this task would involve ongoing research techniques from spotting changes in sequential images. Instead a graphical user interface (GUI) was developed to select the initial object positions. In the future thus GUI will include the tracking algorithms to create a unified platform to visualize detection results.

3. UNDERGRADUATE STUDENTS' COMMENTS

Besides describing the technical aspects of each sub-team project in Section 2, the undergraduate students were also asked, in their own words, to express their opinions about project-based learning through the VIA-VIP vehicle. Their responses are given in Section 3.I. They also provide suggestions for improving the VIP-VIA learning experience, as summarized in Section 3.II.

I. Impression on Learning

The students provided many feedbacks, in their own words, on their impressions on project-based learning, especially in the context of the VIA-VIP classes. They are grouped into different aspects and summarized as follows.

<u>*Multidisciplinary Teamwork*</u>

All VIA team members asserted that VIP differs from a conventional course due to the nature of the course's goal. In a VIP class, the students are taking on problem domains that are relatively new and possibly unsolved. The VIP course is therefore more hands-on and requires students to address research issues from different perspectives. The focus is on combining theory and complex techniques into a multi-semester project that solves new and interesting problems. Conventional courses can also include projects, but these projects are usually smaller and narrower in scope with tight deadlines and are often rigidly defined.

Working in consistent and multidisciplinary groups, as opposed to entirely individually, is a tenet promoted by the VIP program that is more commonly seen in industry than in academia. Presenting results, findings, and techniques to advisers or other members is a regular occurrence, as well. For example the coupling of an EE student and a CS student in the keyframe annotation and player tracking projects works very well and last for over four semesters.

<u>*Vertically-Integrated Projects*</u>

A strong element of the VIP program is the continuation of a project through passing down of knowledge and work from experienced members to newcomers. Diligent logging of meetings, lectures on important topics, and work done in design notebooks furthers this end by providing detailed notes on all aspects of the project. VIP projects usually have a longer lifetime than traditional class projects. The idea is to build up a set of tools that will continue to be developed across semesters. These tools will potentially be used by future VIP students. Additionally, because most students stay for at least two semesters, students have a strong motivation to invest time and effort into their projects. This is because they will likely continue working with these projects in future semesters. Projects aren't just about grades. Projects are actually intended to be applied to real-world problems and used by current and future members.

By design, the teams are formed vertically integrated. Because of the intimate relationship developed between undergraduates and their mentors and faculty advisers, VIA-VIP might be an answer to providing students with a more immersing experience in engineering practice and software development rather than relying on single semester classes.

Another important element to VIA-VIP is the real-world application. Not only are the projects potentially marketable if successful, but also in working on projects, students learn to use tools and libraries that execute the theory learned in other classes or in VIP work. The connection between traditional homework problems to a working product is crucial and of key importance to the VIP program.

<u>*Long-Term Learning*</u>

Project-based courses, like VIP, have a key benefit over traditional classroom learning for the long-term commitment for all parties involved in the project. Even term projects in traditional classes can only last a few months. VIP involves starting a project and continuing it over a longer period of time, changing techniques and focus as time progresses. The cross-semester nature of the projects makes the execution more flexible and highly tolerant to different approaches to solving the problems related to the projects.

Developing a sustaining long-term working relationship with project partners and advisers can prove just as valuable as exposure to new techniques and theory. The VIA-VIP course provides students with a different approach to learning complex materials. In contrast to the traditional classes, VIA-VIP emphasizes on the concept of teaching to complete a long-term project. These projects mimic real-world engineering practices, where students are faced with an application challenge, most often without the necessary knowledge and background to solving them. Students get an opportunity to develop their engineering practices and programming skills, working together in a multidisciplinary team, each providing their inputs and expertise.

For example, the keyframe annotation project was divided into pieces, where each module, from keyframe extraction to classification, was gradually tackled over time through a process of learning, experimenting, and refining. Project-based learning gives students an incentive to not only learn the materials, but also try to apply it in solving the real-life problem set before them, further cementing the foundational concepts (or at least provide avenues of questioning for certain pieces they did not fully understand). By adopting such a gradual step-by-step problem-solving methodology, students would make the necessary connections from all the exploration, troubleshooting, and attempts when things are not working right, while knowing that their contributions would significantly help to reach the goals of the project. There is never a shortage of VIA-VIP problems to work on. The entirety of keyframe annotation is hard to not only implement, but also learn and understand the core concepts and ideas that encompass each module. Only a long-term involvement and commitment from all team members can address this type of project topics.

<u>*VIA-VIP Research Topics*</u>

In terms of curriculum, the VIP courses tend to be more practical than traditional courses in many ways. Students focus on learning techniques and doing research that is relevant to their projects. Usually, a typical course has many concepts and theories that aren't applicable to the projects you work on; in contrast, the VIP curriculum focuses on concepts that are applicable to the specific kind of projects being developed for the course. Despite this strong focus, the VIP curriculum still manages to cover a broad range of concepts; it is just that this broad range of topics all applies to the specific domain of video image annotation.

VIP distinguishes itself from traditional courses through the way in which course lectures and classroom time is organized. The VIP class meets once a week as a class for lecture and once a week as a team with instructors (i.e., doctorate students and faculty) to discuss only things related to projects. This schedule works well because each team gets to meet face-to-face with the instructors and discuss important concepts, the progress of the project, etc. The level of instructor-student interaction achieved here is rare. Students usually do not get such interaction with instructors in a normal class due to the size of the classes. Meeting for only a few hours a week provides students with more free time to pursue project goals.

According to one student who leads a sub-team, it has been observed, in first-hand, how project-learning courses, like VIA-VIP, impacts undergraduates. During the sophomore and junior years, VIP pre-exposes these students to fundamental skills that can be applied throughout their collegiate, as well as post-collegiate, careers. For many of the undergraduates, these types of hands-on projects have introduced them to programming and navigating on a Linux platform, working with a debugger in development tools (e.g., MATLAB, Visual studio, and gcc), creating GUI's for displaying results, and gaining experience with industrial toolkits, such as HTK [12]. The students are also introduced to the process of conducting research, and writing and presenting results, which is something most students are only exposed to at the graduate level. The VIP courses introduce in-depth topics and further applications of regular course materials, such as machine learning and signal processing; many of which are only partially covered in their regular courses. Another aspect is that this grants students the opportunity to directly interact with faculty at a research level and narrows the gap that exists between them.

According to another student, the entire experience in VIP is extremely fluid. VIA has set no rigid framework or syllabus that details how and when goals are to be met. At many moments, certain work does not meet expectations, and often, entire new techniques are devised during the engineering process, requiring additional learning and effort on the students' part. Lastly, there is a heavy emphasis on teamwork because two or more students develop certain pieces of the project over the entire project span, eventually combined into a complex and working system for the real-life problems of interest. This is rarely the case in conventional classroom projects.

In addition, according to a master student who leads another sub-team, the VIP course helps to significantly improve both mentoring and teaching skills while advancing in the research area. By presenting and explaining the research to the undergraduates, the student inadvertently gains a deeper understanding of the material as well. This experience is extremely beneficial to preparing a graduate student to become a future faculty and research professor. This process may also lead to advances and publications. Exposure to ongoing research and internship opportunities for beginning undergraduates provides a real-life, hands-on experience with graduate students and faculty members. Those students who have had previous exposure to research, such as VIA-VIP, have the advantage to fit in well to their careers and are more likely to pursue graduate degrees.

II. Improvement to the Course

The VIA-VIP courses are becoming more diverse with students from various backgrounds and majors. This yields a challenge with lecturing since some students are not as familiar with concepts as others, especially for topics in VIA. In order to assure the topics covered in the project, lectures are appropriate for all students, and a first-week diagnostics and weekly evaluations can be administered to properly gauge the understanding and academic level of students in the VIA-VIP courses. This would allow students to be divided into groups for attending lectures of differing complexities to better adapt to the diversity of the team.

The VIA-VIP program would benefit from assuring that all sub-team projects are of comparable scope with reasonable difficulties in understanding and application. The applicable techniques behind the player tracking project are reasonable to research and understand, for example. As for keyframe annotation, however, the topic involves a substantially more complex theory and code base. Therefore the success and continuation of projects is related to students' ability to tackle such problems. So, one should be careful when finding a long-term project to provide a reasonable starting point for all students regardless of new or continuing team members. This will increase the possibilities of a project to continue over many semesters. On the other hand, VIP is currently set as an optional course where students can take at any semester, for however long they wish. We believe that, to make it more effective, at least two consecutive semesters are required to ensure the long-term and deep involvement of research as well as reinforcing real-life engineering practices.

4. DOCTORAL STUDENTS' OBSERVATIONS

As a key link between instructors and VIA-VIP project members, two doctoral students have been recruited to work with the undergraduate students on the VIA-related topics. They provide face-to-face learning opportunities to students while assisting faculty. They set weekly sub-team meetings to monitor individual sub-team progresses. Through this regular meetings and e-mail discussions, needed techniques, tools, and references related to a given project have been delivered to undergraduate students on a continuing basis.

Based on their experiences as PhD research students who have been leading sub-teams from the onset of the VIA-VIP course, the primary factor to determine whether a project becomes valuable to undergraduate students as well as to the overall project itself is how well a sub-team project is defined. This can be understood that undergraduates are usually more exposed to well-structured, regular courses.

However, because of the unique characteristic of the VIA-VIP class, students often have to build a theoretical foundation and implement a certain concrete deliverable simultaneously, which can overload the students. Usually, it takes more time than expected for undergraduate students to digest theories. On top of this learning load, some sub-teams might first produce unsatisfactory results, or even run into a dead-end. Based on their experiences over the last two years, these difficulties severely limit students' participation in the class. To address these problems, they had to adjust the goal of each of the project topics as they progress. Moreover, they often had to test research ideas on their own before allocating the ideas to the students.

Despite all of the aforementioned difficulties, the PhD students expressed that they have learned a lot from the VIP classes in two aspects: teaching experience and research. First, about how to find interesting problems that lead to the goal of a project far in advance, it is totally different from what are used to do as PhD students. Secondly, they found that they have worked with undergraduates more closely than as TAs in regular classes. Understanding the skill sets of individual students, such as familiarity of required techniques and theories from the required classes, and programming skills, is crucial to determine the success of the each sub-project. After all, based on our experiences, these closed-loop interactions with students make them feel great accomplishments when the students learn fast and deliver tangible outcomes by each semester's end.

Overall, the VIA-VIP class offers learning opportunities not only for undergraduates but also for graduates as well. The PhD students often started with trial and error and end up being able to handle the challenges and take advantages from them. We feel the PhD students have accomplished their main goal of teaching undergraduates interesting project topics, while acquiring useful information from their experiments. Again, careful design of the projects is crucial.

5. INSTRUCTORS' PERSPECTIVES

In contrast to conventional in-class teaching, VIA lectures need to be structured with a moderate level of complexity so that they can be absorbed quickly by the undergraduates and be used right away in their projects. Most of the techniques required in the VIA-VIP projects, shown in the right column of Table 1, require an intensive effort to learn on the students' part. Therefore instructors in the VIA-VIP class had to address great new challenges. We were very pleased to see these complex techniques be implemented correctly and serve their purposes as working and reusable modules for project topics shown in the left column of Table 1. This can never be accomplished so quickly in a traditional one-semester project. Furthermore without the PhD students' direct and long-term involvement in passing down knowledge and correcting some of the implementation bugs on a daily basis, many of modules can never be put into practical usage.

The multidisciplinary nature of the team composition also works out very well. One team has one member from engineering and the other from computer science. They worked together for almost five semesters and formed a tight bond of great partnership. This is very different from the independent research nature for PhD-level graduate students. We believe the VIP students will benefit from this teamwork training when they enter the new workforce of the 21st century. In addition they also played key mentorship roles in bringing new members up to speed to make contributions – as intended by the long-sustaining nature of the VIP-VIA projects.

The long-term engagement of members and continuing flow of newcomers are two crucial factors to ensure good outcomes from project teams. We believe a minimum of two semesters is required to achieve project stability and reduce uncertainties in executing many team projects. Moreover, classes in the current VIA-VIP setting require an intensive involvement from both the doctoral students and instructors. The university administration system has to be willing to support project-based learning courses, like VIA-VIP, and issue proper teaching credits and incentives to encourage faculty's active participation and imaginative initiatives. It is simply too resource-demanding to make VIA-VIP courses with such a tight coupling of faculty-student engagement working to benefit all parties involved in this meaningful education endeavor.

6. CONCLUSION

The Vertically-Integrated Projects (VIP) Program is an engineering education program that operates in a research and development context. Undergraduate students that join VIP teams earn academic credit for their participation in design efforts that assist faculty and graduate students with research and development issues in their areas of technical expertise. The teams are often multidisciplinary, vertically-integrated and long-term in nature. Although we foresee many enhancements needed to make project-based learning courses like VIA-VIP grow and succeed, we are also pleased to witness undergraduate and graduate students learning skills that will greatly benefit them early and throughout their industrial and academic careers.

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