Measuring Individual Differences in Visual and Verbal Thinking Styles

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Abstract

Do people have dispositions towards visual or verbal thinking styles, i.e., a tendency towards one default representational modality versus the other? The problem in trying to answer this question is that visual/verbal thinking styles are challenging to measure. Subjective, introspective measures are the most common but often show poor reliability and validity; neuroimaging studies can provide objective evidence but are intrusive and resource-intensive. In previous work, we observed that in order for a purely behavioral testing method to be able to objectively evaluate a person's visual/verbal thinking style, 1) the task must be solvable equally well using either visual or verbal mental representations, and 2) it must offer a secondary behavioral marker, in addition to primary performance measures, that indicates which modality is being used. We collected four such tasks from the psychology literature and conducted a small pilot study with adult participants to see the extent to which visual/verbal thinking styles can be differentiated using an individual's results on these tasks.

Keywords: Cognitive styles; mental representation; processing style; representational modality

Motivation

I think in pictures. Words are like a second language to me. I translate both spoken and written words into full-color movies, complete with sound, which run like a VCR tape in my head.... Language-based thinkers often find this phenomenon difficult to understand, but in my job as an equipment designer for the livestock industry, visual thinking is a tremendous advantage. (Grandin, 2008, p. 3)

Temple Grandin is a well-known professor of animal science who is also on the autism spectrum. She has observed that she is a "visual thinker," in the sense that she has a disposition towards using visual mental representations instead of verbal ones. She still has access to verbal representations (e.g., language), but at least introspectively, her dominant mode of thinking seems to be visual, not verbal (Grandin, 2008).

Other introspective accounts of this kind of "visual thinking style" in autism have been documented (Hurlburt et al., 1994). In addition, there is objective evidence from both behavioral and neuroimaging studies that at least some individuals on the autism spectrum do use visual mental representations for certain tasks that are solved verbally by typically developing controls (Kunda & Goel, 2011). Other evidence from autism seems to suggest that individuals on the spectrum may show a more bimodal distribution across extremes of visual and verbal thinking than do typically developing individuals (Joseph et al., 2002).

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Among typically developing individuals, people can successfully be instructed to use one modality over another to solve the same given task (Reichle et al., 2000). Investigations of the learning styles hypothesis suggest that a person's preferred visual/verbal thinking style, i.e., "default" representational modality, is distinct from visual/verbal cognitive ability, i.e., the proficiency with which a person can solve visual or verbal problems, and also from visual/verbal learning preferences, i.e. whether a person prefers to receive visual or verbal instructional materials (Mayer & Massa, 2003).

These observations collectively raise a very important question: Do individuals indeed have dispositions towards visual or verbal thinking styles, in the sense that they reliably exhibit a tendency towards one default representational modality versus the other?

Many interesting questions follow from this one. To what extent do people with certain cognitive conditions like autism show different distributions over thinking styles than do typically developing individuals? Do these different thinking styles represent important etiological subtypes, i.e. "cognitive phenotypes" within autism or other conditions (Charman et al., 2011)? To what extent do differences in thinking styles affect how students learn from different instructional materials (Pashler et al., 2008)? How do individual differences in the *flexibility* with which people can switch away from their default representational modality contribute to overall metacognitive abilities? (And so on.)

The Problem: How to Measure?

The problem in trying to answer this question is that visual/verbal thinking styles are challenging to measure. Subjective, introspective measures do exist, such as the Verbalizer-Visualizer Questionnaire (VVQ), which asks test takers to agree or disagree with statements such as, "My dreams are extremely vivid," and "I don't believe that anyone can think in terms of mental pictures" (Richardson, 1977). Many studies have attempted to use these and other subjective measures to study visual/verbal thinking styles and to relate these differences to other variables. However, while introspection can be valuable for studying human cognition, these approaches often exhibit poor reliability and validity (Antonietti & Giorgetti, 1998).

An objective measure of visual/verbal thinking styles can be obtained by observing a person's brain activity using fMRI or other neuroimaging techniques, as visual mental representations are instantiated in the visual processing regions of the brain, and verbal mental representations are likewise instantiated in auditory and linguistic processing regions (Reichle et al., 2000; Kana et al., 2006). However, neuroimaging is resource-intensive and cannot easily scale to large numbers of participants or flexible testing settings.

Researchers have repeatedly called for improvements in this area, emphasizing the need for objective, reliable, easy-to-administer measures (Riding & Calvey, 1981) and suggesting that certain negative results in the literature surrounding the idea of visual/verbal thinking styles may be due to the paucity of effective measures in the past (Kaufmann, 1981; Pashler et al., 2008). As a result of this gap, we know surprisingly little, in terms of objective and reliable research findings, about individual differences in visual/verbal thinking styles, including whether most individuals indeed even have dispositions towards a "default" representational modality.

Our Approach

In order for a task or testing method to be able to *objectively* evaluate a person's visual/verbal thinking style, the task must meet two key criteria (Kunda & Goel, 2011):

A. The task must be solvable equally well using either visual or verbal mental representations. If a task can only be solved using one type of representation, then a person's performance on that task can only reflect the level of their ability on that particular task, not their thinking style. For example, a person might have a strong visual thinking style, but when given no other choice, can switch to using verbal mental representations. Only by providing both options can a task measure modality preferences/biases.

B. The task must offer a *secondary marker* of some kind, in addition to primary performance measures, that indicates which modality is being used. Neuroimaging methods, for example, provide these secondary markers in the form of measurements of brain activity in different regions. We focus on identifying secondary markers that are behavioral, so that they can be measured without neuroimaging.

We have identified four such tasks that already exist in the psychology literature:

Task 1. Serial digit recall. If someone reads you a list of numbers, and you are asked to repeat them back, do you use your visual or verbal memory buffer to store the numbers? While digit recall is sometimes assumed to be a test of verbal working memory, there is evidence that people can use either visual or verbal memory for this task (Kunda & Goel, 2011).

A secondary behavioral marker can be obtained by giving someone a visual or verbal suppression task (a task known to recruit either visual or verbal cognitive resources) to perform simultaneously with digit recall (García-Villamisar & Sala, 2002). Under this "dual task" paradigm, if a person can do the two tasks simultaneously and well, then the tasks are assumed to recruit different pools of cognitive resources. If performance suffers on either task, then the tasks are assumed to recruit the same pool of cognitive resources.

Thus, if someone can still recall digits under visual suppression but not as well under verbal suppression, then they are likely to be doing digit recall verbally. If, on the other hand, they cannot recall digits as well under visual suppression but can under verbal suppression, then they are likely to be doing digit recall visually.

Task 2. Serial picture recall. If someone shows you a series of object pictures, and you are asked to repeat the objects back, do you use your visual or verbal memory buffer to store the information? There is evidence that people can use either visual to verbal representations for this task, and in particular, there is a developmental progression from visual to verbal representations in typically developing children (Hitch et al., 1989).

The secondary behavioral marker is obtained by giving people lists of objects that are either visually similar, phonologically similar, or not similar along either dimension. If a person's accuracy decreases for visually similar stimuli but not for phonologically similar stimuli, then it is likely that they are using visual representations, which would be susceptible to inter-stimuli interference from visually similar objects. If, on the other hand, a person's accuracy decreases for phonologically similar stimuli but not for visual, then it is likely that they are using verbal representations for the task.

Task 3. Arithmetic task switching. Task-switching is an executive ability often studied using arithmetic, i.e., a person alternately adds and subtracts pairs of digits. Arithmetic task-switching is often thought to involve verbal cognitive resources, but there is evidence that people can use either visual or verbal resources for the task (Kunda & Goel, 2011).

As with serial digit recall, task switching is often studied using the dual task paradigm, by giving people either visual or verbal suppression tasks and then observing the effects of each type of suppression on performance (Emerson & Miyake, 2003; Whitehouse et al., 2006).

Task 4. Sentence-picture verification. If someone shows you a simple sentence like, "The star is above the plus," followed by a picture of a star and plus, and you are asked to say whether the sentence and picture match or do not match, how are you making this determination? Are you converting the sentence into a mental picture, and then comparing your mental picture with the actual picture? Or are you remembering the sentence using verbal representations, and then converting the actual picture into verbal representations as well in order to make the comparison verbally?

Various patterns of reaction times can be used as secondary behavioral markers to determine which strategy a person is using. For example, most people take longer to verbally process a negative sentence like, "The star is not above the plus," than the equivalent, affirmative sentence, "The plus is above the star." For a person solving this task verbally, their reaction times upon inspecting the picture should be longer for negative sentences than for affirmative sentences. However, for a person solving this task visually, by the time they start inspecting the picture, they have already converted either type of sentence (negative or affirmative) into the same mental picture, and so their picture-inspection times should be the same across negative or affirmative initial sentences.

Very detailed studies have found several such reaction time effects in typically developing adult samples (Carpenter & Just, 1975), including the presence of what appear to be distinct visual and verbal groups (MacLeod et al., 1978). People can also switch strategies on purpose, and the interpretations of resulting reaction time patterns have been confirmed through neuroimaging (Reichle et al., 2000).

Complexities

In an ideal world, we should be able to give a person any one of the four tasks listed above, measure whether they are using visual or verbal mental representations, and be done with it. However, there are many complexities that make this problem even more challenging than it already appears to be.

Inter-task variability. Would a person with a visual thinking style be expected to use visual mental representations across all of these tasks? Perhaps, but perhaps not. If individuals are able to develop different overall dispositions towards visual/verbal thinking, it seems entirely possible that they could develop more localized dispositions for certain classes of tasks. In this case, it may be that a person's visual/verbal thinking style should be characterized more like a visual/verbal thinking *profile*, defined across task types.

Another complexity arises if we consider whether each task is measuring an active preference *toward* a particular modality versus a more passive inability to switch *away from* a particular modality. For example, on the sentence-picture task, there is no particular advantage related to either modality, and so the task is more like a measure of preference.

However, tasks that use the dual-task paradigm are different in that they are essentially placing the person under duress, and then we are measuring whether they have the ability to switch to a different modality under those conditions. In a way, these dual-task setups are a measure of a person's cognitive flexibility, not preference. (Our task 3 on picture recall, looking at errors due to stimulus similarity, could be a measure of preference or flexibility depending on how aware the person is of their performance levels.)

More generally, visual/verbal thinking styles can be differentiated into 1) a person's capability to use visual or verbal mental representations on demand, 2) a person's temporary preference for one or the other, or 3) a person's long-term, habitual use of one or the other (Antonietti & Giorgetti, 1992).

Dual task demands. It is difficult to design dual task studies in which the visual and verbal suppression tasks are of comparable complexity, interact with visual/verbal strategies on the main task in comparable ways, and are physically possible for a person to do simultaneously with the main task. We have loosely described simultaneous tasks as using (or not using) "the same pool of cognitive resources," but this is obviously a simplification; actual task interactions are much more nuanced and complex (Pashler, 1994).

In addition, these dual task studies do not just measure a person's visual/verbal thinking styles; they are also measuring a person's dual tasking ability. Consider the schematic

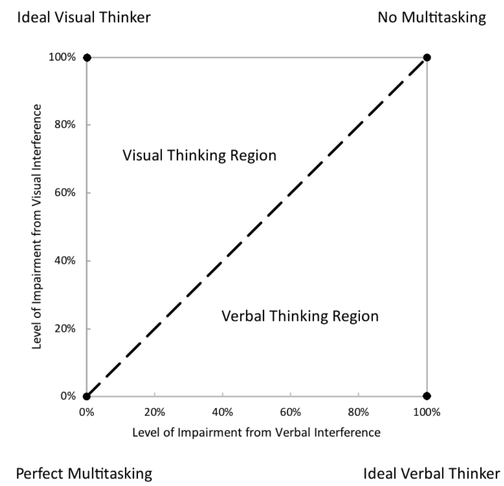

Figure 1: Schematic showing the space of possibilities into which a person's visual/verbal dual-task scores might fall. Top-left point: The "ideal" visual thinker who is fully impaired by visual suppression but completely unaffected by verbal suppression. Bottom-right point: The "ideal" verbal thinker who shows the opposite pattern. Bottom-left point: The perfect multitasker who is unaffected by visual or verbal suppression. Top-right point: A complete inability to multitask, i.e., full interference from both suppression conditions.

shown in Figure 1, which illustrates how a person's dual task scores actually place them along two dimensions of variation, not just one: one dimension (perpendicular distance from the dotted line) measures the relative effects of visual vs. verbal suppression, while the other dimension (distance along the dotted line) measures the overall effects of dual tasking.

Individual versus group differences. All four of the tasks we adopt appear to have primarily been studied in the context of group differences. One study of the sentence picture task does sort individuals into visual and verbal groups, but they use a clustering algorithm that incorporates data from all participants (MacLeod et al., 1978). How to extract enough "signal" from the relatively small amount of data coming from a single participant is an important open question in our work.

The obvious solution of collecting more data from each person adds another layer of complication: will people's default thinking styles change with practice? One might expect greater effects of practice on tasks that are measuring modality inflexibility (like the dual task setups) than on tasks that are just measuring preference (like the sentence picture task).

Methods

While we could no doubt fill up this entire paper with a list of complexities, at some point one must forge ahead with an experiment, to engage with these issues more concretely. We conducted a small pilot study with 12 adult participants recruited from the Vanderbilt University community (8 male and 4 female, with an average age of 27 years). Participants

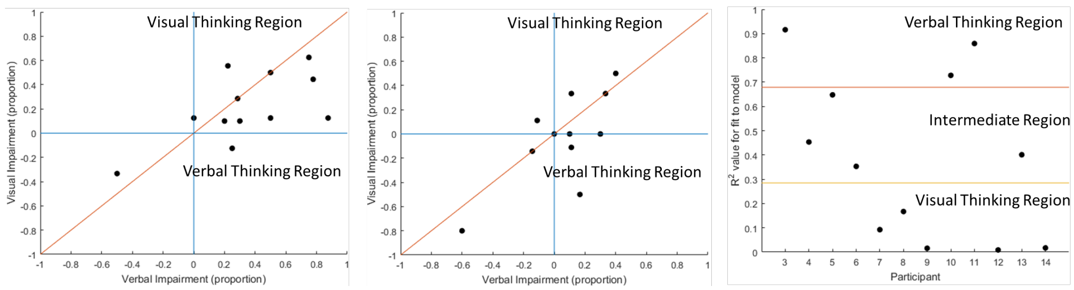

Figure 2: Levels of impairment (decreases in accuracy) on digit recall (Task 1, left) and picture recall (Task 2, center). Degree of fit (R^2) with verbal processing model (MacLeod et al., 1978), with thresholds adopted from this original study (Task 4, right).

received a gift card as compensation for their time.

After completing a brief demographic questionnaire, participants were asked to perform the four tasks, with the order of tasks counterbalanced across participants. Then, participants were asked to complete two introspective, subjective questionnaires: the Vividness of Visual Imagery Questionnaire (VVIQ) (Marks, 1973), and the Verbalizer-Visualizer Questionnaire (Richardson, 1977). All tasks that require computerized elements were created with the open-source experiment software PsychoPy (Peirce, 2007). (Note that we omit further discussion of the VVIQ measure and results here, as vividness of imagery is not the focus of this paper.)

What follows is a highly abbreviated description of our task designs and analysis methods. Due to space limitations, we cannot detail our full methods here; we did aim to match the original studies' methods as closely as possible. Where applicable, the ordering of conditions was counterbalanced across participants, and most tasks also included initial practice phases as well as checks for atypical object labeling (Task 2, picture recall) and letter labeling (Task 1, letter rhyming suppression task).

Task 1: Digit recall. We tested each participant's digit span using standard procedures. Then, 10 sequences at span were given as a baseline condition, following by 10 sequences under visual and verbal suppression. Accuracy was measured as number of sequences correctly recalled.

Visual suppression took the form of a printed grid-based labyrinth on paper, in which the participant is instructed to mark X's in each box to complete as long a path as possible (García-Villamisar & Sala, 2002). We designed a new verbal suppression task for this study; we wanted a manually performed task, since the primary task required spoken responses. We printed a sheet with 40 pairs of letters, of which some rhymed (like "A" and "K") and some did not (like "E" and "R"). Participants had to mark whether each pair rhymed.

Task 2: Picture recall. Picture stimuli in this task consisted of 27 images of common objects. Unbeknownst to the participant, the images were grouped into three categories: visually similar images (similar shape and orientation) with phonologically dissimilar labels, visually dissimilar images with phonologically similar labels (rhyming vowel sounds), and images with neither type of similarity (Hitch et al., 1989). Participants were then shown two sequences of five images in each category and asked to recall them. Accuracy was measured as the percentage of pictures correctly recalled at the correct place in each picture sequence.

Task 3: Arithmetic task switching. In this task, participants completed three types of arithmetic exercises on paper across three experimental conditions. The arithmetic exercises were to 1) add 30 pairs of numbers, 2) subtract 30 pairs of numbers, and 3) switch between adding and subtracting 30 pairs of numbers. The second number was always three, and the operation signs were not shown on any of the sheets (Emerson & Miyake, 2003). The experimental conditions were baseline (no suppression), visual suppression, and verbal suppression. So each participant completed a total of 9 sheets.

Verbal suppression involved repeating the word "Monday" about once per second. Visual suppression involved first (before the sheet) looking at two circular gratings (presented at 20°, 70°, and 115°orientations), completing the sheet, and then selecting which of two new gratings had changed since the previous presentation.

We measured total time taken to complete each sheet. To analyze results, we first calculated the average time for individual adding and subtracting operations in the control and suppression conditions, separately, by taking the total time and dividing by the number of operations (thirty). Then, we were able to calculate the average time taken to switch in each condition with the following formula:

$$avg_{switch} = \frac{total_{switch} - (avg_{add} * 15) - (avg_{sub} * 15)}{29}$$

Note that there are 29 switches for a list of 30 number pairs.

Task 4: Sentence picture verification. The participant is presented with a sentence that describes a spatial relationship, such as "The plus is not above the star," which advances at user input, and then a picture with a spatial relation that may or may not match the sentence. The participant must respond with whether or not the sentence matches the picture. Each participant completed two blocks of 64 trials each.

Following previous methods, we computed how well each participant's reaction times fit a verbal processing model

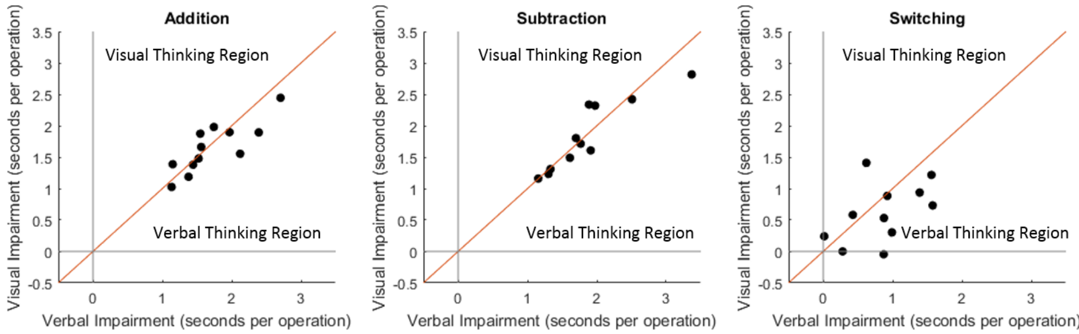

Figure 3: Levels of impairment (average increases in reaction time per operation) under visual and verbal suppression on three conditions given in arithmetic task (Task 3): all adding, all subtracting, and switching between adding and subtracting.

(MacLeod et al., 1978); please see the original study for more details. The resulting R^2 values from the original study were clustered into three groups: well-fit (i.e., verbal thinkers), poorly fit (i.e., visual thinkers), and intermediate fit. Because we did not have enough participants to support a clustering analysis, we used the R^2 thresholds from this original study as rough estimates of group boundaries.

Results and Discussion

Here, we present a bird's-eye view of results from this study. (Due to space limits, we cannot report on many details.)

Figure 2 shows data for our 12 participants on Tasks 1 (digit recall), 2 (picture recall), and 4 (sentence picture verification). Note that for tasks 1 and 2, we get separate measures of impairment (decreases in accuracy) due to visual/verbal suppression (task 1) or similarity (task 2), and so each participant is represented as a 2D point. Negative scores on these two tasks indicate participants who were more accurate under suppression than on the baseline task, which may reflect practice effects, general noise, or reallocation of cognitive resources to a different modality. For task 4, we get only a unidimensional score for each participant.

Figure 3 shows data for our 12 participants on the three different arithmetic exercises that were part of Task 3: addition, subtraction, and switching. These points illustrate impairment from visual/verbal suppression (increases in average reaction time per operation). The switch times are calculated after taking into account potential effects of suppression on the add and subtract operations themselves, according to the equation provided in the Methods section.

Figure 4 shows a similar two-dimensional mapping of participants response scores from the Visualizer-Verbalizer Questionnaire (VVQ). The x-axis represents participants' average ratings of "verbal" statements from the VVQ, and the y-axis represents average ratings of "visual" statements.

Just based on qualitative inspections of these graphs, it appears that digit recall and task switching (and perhaps, to a lesser extent, addition by itself) recruit participants' verbal processes more than their visual processes. The introspective VVQ is the only task that seems to show a visual preference for most participants. Participants are more mixed for the picture recall task, sentence picture verification, and subtraction.

To investigate consistency within subjects and across tasks, we computed each participant's perpendicular distance to the visual/verbal divide. For the sentence picture task, we computed each participant's distance from the midpoint of the two thresholds. These distance scores are shown in Figure 5. Positive scores indicate a verbal thinking style, and negative scores indicate a visual thinking style. Zero values in these bar graphs indicate that a participant was right on the line (though where on the line we cannot say from these bar graphs). Participant 10 was missing data for task 3; all other "invisible" bars represent zero values.

Only two of our participants (3 and 9) are completely consistent across tasks, and both fall in the verbal thinking category. This might be expected from our sample; for example, the picture recall task shows a typical developmental progression from visual to verbal processing, and most or all of our participants were likely typically developing (we did not ask).

Continued research into developing an objective, quantitative, and reliable measure of visual/verbal thinking styles is sorely needed. Studies of this kind with larger and more varied samples will yield more insights into effect sizes, etc. In addition, convergent studies using neuroimaging on the same or similar tasks would provide a means of validation.

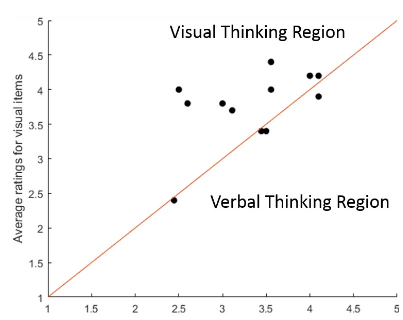

Figure 4: Average ratings (on a scale of 1-5) of affinity/preference for visual and verbal items on the Verbalizer-Visualizer Questionnaire (Richardson, 1977).

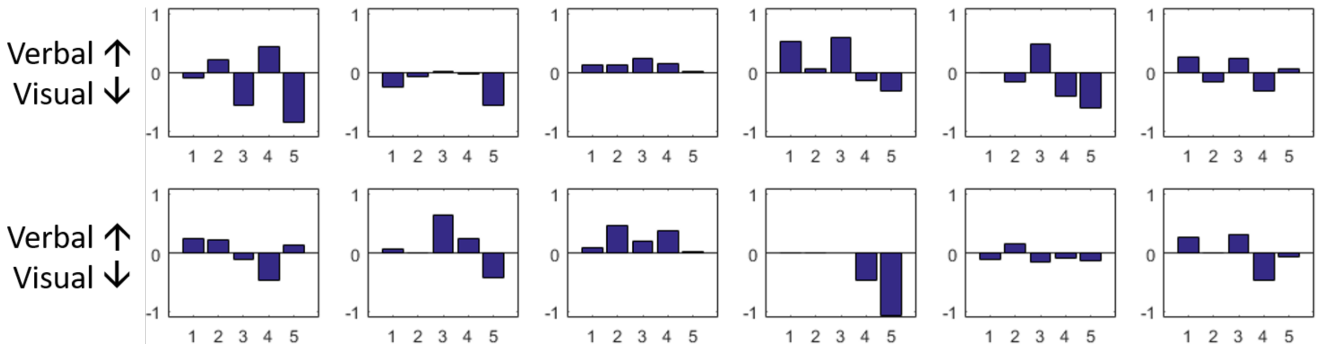

Figure 5: For each of 12 study participants, calculated distance from visual/verbal “midline” on four main tasks: 1) digit recall, 2) picture recall, 3) task switching, 4) sentence picture verification, and also on 5) VVQ. (Across-task magnitude comparisons are not to scale.) +1 is the score for the ideal verbal thinker, and a -1 the score for the ideal visual thinker.

Acknowledgments

Thanks to Brandt Plomaritis, Josh Palmer, Harsha Vankayalapati, and Frank Tong. This research was supported in part by the National Science Foundation (Grant #1730044) and by the Vanderbilt University School of Engineering (VUSE) Summer Research Program.

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