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COMPUTATIONAL DIVERSIONS

Bead Games, or, Getting Started in Computational Thinking Without a Computer

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Recently my wife brought home from the library a charming book by Phillip Done, an elementary school teacher from California, called *Close Encounters of the Third-Grade Kind* (Done 2009). The book is rich in anecdotes drawn from the author's long experience in the classroom, and acts as a wonderful complement (or maybe a tonic alternative) to reading in educational research. Done doesn't write like a researcher, but his tales are filled with the sounds and smells and emotions of the classroom, and he has–or has developed over time–tremendous insight into the personalities of the children with whom he works.

The purpose of this column is not to review Done's book (which in any event I haven't yet finished) but to note that much of his experience and accumulated wisdom is about *stuff*–about the physical materials of teaching. He knows about construction paper, and glue, and thumbtacks, and a million other objects of the trade. At the outset of *Close Encounters*, he suggests coining the word *teacherhood* (by analogy with "motherhood" or "fatherhood"), and writes:

> *Teacherhood* is knowing that when kids hold up their multiplication flash cards to the light they can see the answers on the back,… that you always explain the instructions before handing out the blocks (or beans or marshmallows), that cupcake paper is edible…. *Teacherhood* is prying staples out of the stapler with a pair of scissors… being able to make thirty-seven different things out of a paper plate… making rain parkas out of Hefty bags when it starts pouring on the field trip… (Done 2009, [pp. 4–5])

These are excerpts from a longer list, but they provide a flavor of Done's ability to capture the essence of how things behave, and sometimes misbehave. These are themes that I've occasionally tried to write about before (with far less eloquence), but Done's examples speak to the larger role that tangible materials have in children's and teachers' lives–the

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ways in which they can be appropriated for all sorts of purposes, intellectual, imaginative, and playful. One of my favorite examples occurs toward the end of the book, when the author is listing the things that he learned over the course of the school year:

> If you take a piece of bologna, fold it over and bite the center, you have a bologna monocle. (Done 2009, [p. 317])

Funny as the image is, there's also a world of common-sense knowledge in it: the shape and rubbery texture of bologna slices (you can fold and bite them), the outline left by a good chomp, and the almost irresistible urge to play with things.

What does this all have to do, one might ask, with computational diversions? Well, to change direction for a moment (bear with me here), I have also been involved in numerous discussions of late on the subject of "computational thinking", a notion that has captured the imagination of many computer science faculty. "Computational thinking" is a term popularized by Professor Jeannette Wing of Carnegie-Mellon University, and was elaborated by her in 2006 in a brief but provocative piece in the *Communications of the ACM* (Wing 2006):

> Computational thinking involves solving problems, designing systems, and understanding human behavior, by drawing on the concepts fundamental to computer science. Computational thinking includes a range of mental tools that reflect the breadth of the field of computer science. (Wing 2006, [p. 33])

Wing goes onto sketch a variety of examples of the sort of thinking, or attitude, that she has in mind–understanding the difficulty of a problem, thinking about simulation, or recursion, or search strategies, and so forth. (It's a compelling three-page manifesto; go read the whole thing.) She ends with something of a call to arms for computer science teachers:

> Professors of computer science should teach a course called "Ways to Think Like a Computer Scientist" to college freshmen, making it available to non-majors, not just to computer science majors. We should expose pre-college students to computational methods and models. Rather than bemoan the decline of interest in computer science or the decline in funding for research in computer science, we should look to inspire the public's interest in the intellectual adventure of the field. We'll thus spread the joy, awe, and power of computer science, aiming to make computational thinking commonplace. (Wing 2006, [p. 35])

There have been numerous responses to Wing's argument in the 4 years since the appearance of her article, including a recent workshop report on the subject published by the National Research Council (2010). Personally I'm highly sympathetic to Wing's point of view, but admittedly there's a lot of disagreement among computer scientists about just what "computational thinking" really entails at a nuts-and-bolts level. That is to say, no two colleagues that I've spoken to can agree–even in fairly broad strokes–on what her proposed course should include in a week-to-week syllabus. Still, this is not the occasion for expanding on this debate. What this *is* the occasion for is something a good deal weirder: namely, trying to combine Wing's notion with Done's sense of stuff. My own feeling is that there are many opportunities for small-scale projects, appropriate in some cases to elementary or middle school classrooms, that encourage computational thinking through the use of the sorts of things you find in school cabinets and little plastic bins. Computational thinking can be done, occasionally, in construction paper and yarn and ribbon and buttons. A computer does not hurt for these purposes, but it is not always necessary. There are other media available.

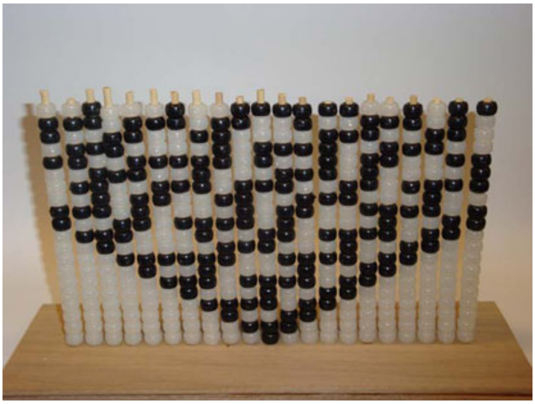


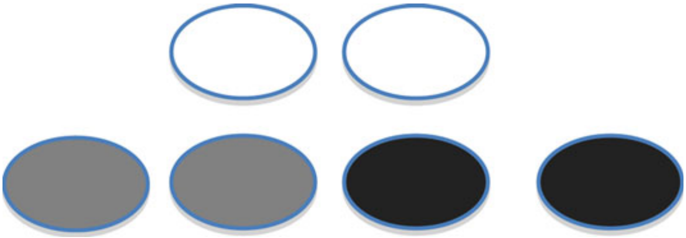
Fig. 1 The "Rule 30" cellular automaton, realized in a black-and-white bead construction stacked on an array of 21 wooden dowels

Take, for example, beads. Beads are a staple of children's activities, and a highly flexible creative medium. They come in all sorts of bright colors, and sizes, and even materials. A trip to the local crafts store will convince the reader that there is a tremendous variety of relatively affordable bead-related supplies, tools, and resources.

As an example of the sorts of "computational" projects one can undertake with beads, consider Fig. 1. This is a black-and-white bead rendering of a one-dimensional cellular automaton–the famous "Rule 30", explored by Stephen Wolfram in his book *A New Kind of Science* (Wolfram 2002), and later described by Wolfram as his "all-time favorite" (Wolfram 2005). To make this construction, I first drilled a series of holes into a wooden frame and inserted some 1/8-inch dowels; then it was simply a matter of placing the beads, according to the table for Rule 30, on each successive level. For example: if, on a given row, there exists a trio of beads two of which are white, then the bead placed above the center of that trio on the next row will be black. In this way, the construction emerges, row by row, starting from an initial pattern (at the bottom) of a single black bead set against a background of white. (The beads themselves, in this case, are the inexpensive plastic sort that come in large bags or tubs at the local crafts store.)

The end result of the Fig. 1 project is an attractive classroom-type display; and the process of its creation would easily be explainable to a middle or high school student. On the other hand–as a practitioner like Done would most likely point out–it's not as colorful as it might be. A natural follow-onto this project, then, would be something like the example shown in Fig. 2. This is a modulo-three Pascal triangle constructed in a similar fashion to the cellular automaton of Fig. 1, but now using several different colors of beads to represent one (black), two (blue) and zero (orange) mod 3. Again, the rules for constructing the pattern are simple: to derive a number value in a given row and column of the triangle, one simply adds (mod 3) the values just below it, to the right and left, in the previous row.

For this construction, a pair of adjacent beads on one row represents a single number value in Pascal's triangle. This technique allows the builder to "stagger" the number values in each successive row. To illustrate the idea: in the diagram below, the "gray" beads in the bottom row might represent a single location for the value 1, the "dark gray" beads in the bottom row might represent a single location for the value 2, and the "white" beads in the row above represent their sum (0) modulo three in the row above:



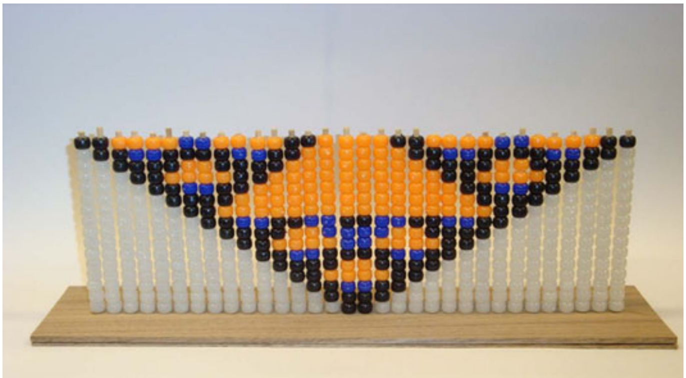


Fig. 2 A modulo-three Pascal triangle represented in beads. Here, the white color represents "unoccupied"; black represents the value 1; blue represents the value 2; and orange the value 0. Each numeric value in the triangle is represented by two adjacent beads of the same color, as described in the text

Constructing the Fig. 2 project itself leads naturally to a desire to experiment with other forms for bead constructions. One might try the same Pascal triangle project with "wraparound", managed by placing the beads on dowels arranged in a circle as in Fig. 3. In this case, the initial row (at the bottom) was started with two "ones" on opposite sides of a circle of ten values, and the standard modulo-3 addition rules were used to construct successive rows. (Another way of putting this is that the initial row of the triangle is 1000010000, and the addition proceeds with wraparound; thus the second row will have a pattern of 1100011000.) It quickly becomes apparent that the rows cycle through the same pattern of values, over and over again, with a period of eight distinct rows in each cycle.

Naturally, projects such as these represent only the very beginning of explorations using beads as computational representations. Indeed, one might think of this sort of play as going back to the very roots of calculation (the word "calculate" itself derives from *calculus*, the Latin word for "pebble"). Likely next steps might include, among others: very large (wall-sized) constructions; or constructions involving vast numbers of colors; constructions employing strings as the substrate on which beads are placed; and many, many more. Just as a hint of still another possible direction for extending these projects, consider Fig. 4: this is a project showing the time evolution of a two-dimensional cellular automaton (the well-known "Game of Life") over four steps.

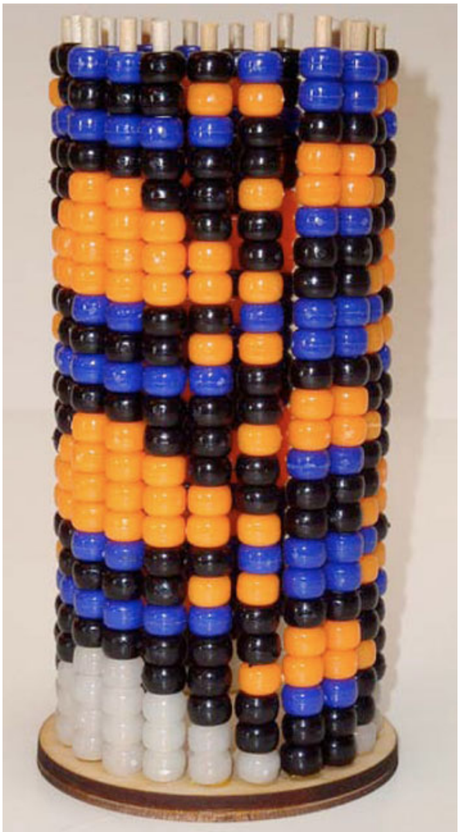


Fig. 3 A design based on the modulo-three Pascal triangle, realized on a cylindrical arrangement of dowels

Here, a set of clear acrylic layers represent the successive times of the automaton; the layers have holes into which large wooden beads (really, spheres) have been placed to represent the “live” cells. The four layers show the successive stages of a Game of Life “glider”.

Beyond the possibility of computational bead constructions, the larger point of these examples–returning to Done’s anecdotes about “classroom stuff”–is to suggest that computational thinking is the province of all sorts of materials. We might note that instead of using beads to represent “pixels” in a home display, one might employ (say) Lego bricks, or small fluffy pompoms, or buttons, or charm-bracelet charms, or M and M’s. Perhaps there are still other “computational thinking” projects to be undertaken with ribbons, yarn, rubber bands, or cake icing (or even slices of bologna). If–as Jeannette Wing suggests–computational thinking is practically ubiquitous, then youngsters should be able to play with that sort of thinking whenever they wish, and using practically anything they might own. Readers who have their own suggestions for “homemade” or “classroom-friendly” computational-thinking projects or displays should feel encouraged to send them to this column at: ijcml-diversions@ccl.northwestern.edu.

Fig. 4 Four layers of wooden beads representing (from top to bottom) successive stages in the movement of a Game of Life "glider"

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References

Done, P. (2009). *Close encounters of the third-grade kind*. New York: Center Street.
National Research Council. (2010). *Workshop Report on the Scope and Nature of Computational Thinking*. Washington, DC: National Academies Press.
Wing, J. (2006). Computational thinking. *Communications of the ACM, 49*(3), 3–35.
Wolfram, S. (2002). *A new kind of science*. Champaign, IL: Wolfram Media.
Wolfram, S. (2005). On starting a long-term company. Transcript of a talk available at: http://www.stephenwolfram.com/publications/recent/ycombinatorschool/.