Developing Physical Manipulatives and Games for Teaching Advanced Data Structures

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SIGCSE Special Project - Funded 2019
Final Report - June 2022

This report summarizes the work to date of the **CS2Mulch** project, which provides engaging manipulatives for demonstrating concepts in advanced data structures to build these mental models. Instructors can use these tools to support lessons on sorting algorithms, binary search trees, heaps, sets, and hash tables.

Two original decks of cards form the basis for interactive classroom games and collaborative peer exercises in CS2. The **Acorns** deck is primarily useful for *sorted* data structures. This deck consists of cards numbered with integers from 00-69. These cards can be overlapped on the corners to demonstrate insertion and removal algorithms for binary trees or heaps. The **Menagerie** deck facilitates *hashed* data structures. This deck consists of cards that display an animal, along with two integers that are the result of passing the name through two simple hash functions, Murmur3 and FNV, modulo 8. Additional cards are numbered 0 to 7, to be used as markers for arrays within hash table implementations. To facilitate the addition of markers as indices in both decks, 26 double-sided **red/black chits** are included, lettered A-Z.

The CS2Mulch decks, along with lesson plans and supporting materials, are freely available through a Creative Commons license at https://mgoadric.github.io/cs2mulch/, either for PDF download, virtually through the online board game software Tabletopia, or for purchase through on-demand printing at The Game Crafter.

Budget

Item	**Projected**	**Actual**
Faculty Stipend	$750	$750
Undergraduate Stipend	$750	$950
Graphic Design	$1500	$1500
Printing of physical decks	$1000	$800
2 x Adobe Creative Cloud	$478	$478
The Game Crafter Component Studio	$120	$120
Total	$4598	$4598

Progress

Work began in Fall 2019 with the hiring of undergraduate Levi West to assist Dr. Mark Goadrich with the development of the two decks of cards. West coordinated the asset uploading to The Game Crafter Component Studio, which allowed us to then export the cards as PDF files or individual PNGs for transfer to Tabletopia. West and Goadrich also began formatting the CS2Mulch website and adding descriptions of each algorithm with detailed image walkthroughs and video demonstrations. In Fall 2019 and Spring 2020, Professor Jessica Hawkins designed the layout and sourced the card art for the Menagerie deck, selected the fonts for the website, and created the physical box design for individual sets.

Multiple copies of both decks were then ordered and tested in the CS2 classroom and labs at Hendrix College in Spring 2020. The original intent of this grant was to follow up and broaden their use to other institutions, however these plans fell through with the advent of COVID-19 in March 2019, which diverted much of the attention of many professors and severely limited the ability to use physical manipulatives in online learning environments. Progress instead continued with testing and implementing the decks in Tabletopia while Hendrix remained virtual in Fall 2020, and more decks were ordered to facilitate social distancing requirements for Spring 2021. At SIGCSE 2021, Goadrich presented a virtual demonstration of the CS2Mulch materials using Tabletopia and referencing the online resources. To help complete all the planned algorithms for this project, Thomas Sebring was hired in Fall 2021 to create and record the remaining examples and videos.

CS2Mulch Algorithms With Resources

Acorn	Menagerie
SORTING Gnome Sort Bubble Sort Insertion Sort Quicksort Mergesort BINARY SEARCH TREES Insert Remove Rotations Traversals HEAPS Insert Remove	SEPARATE CHAINING Insertion Deletion LINEAR PROBING Insertion Deletion ADDITIONAL HASHING Cuckoo Hashing

Figure 1) Separate Chaining Hash Table constructed with the Menagerie Deck

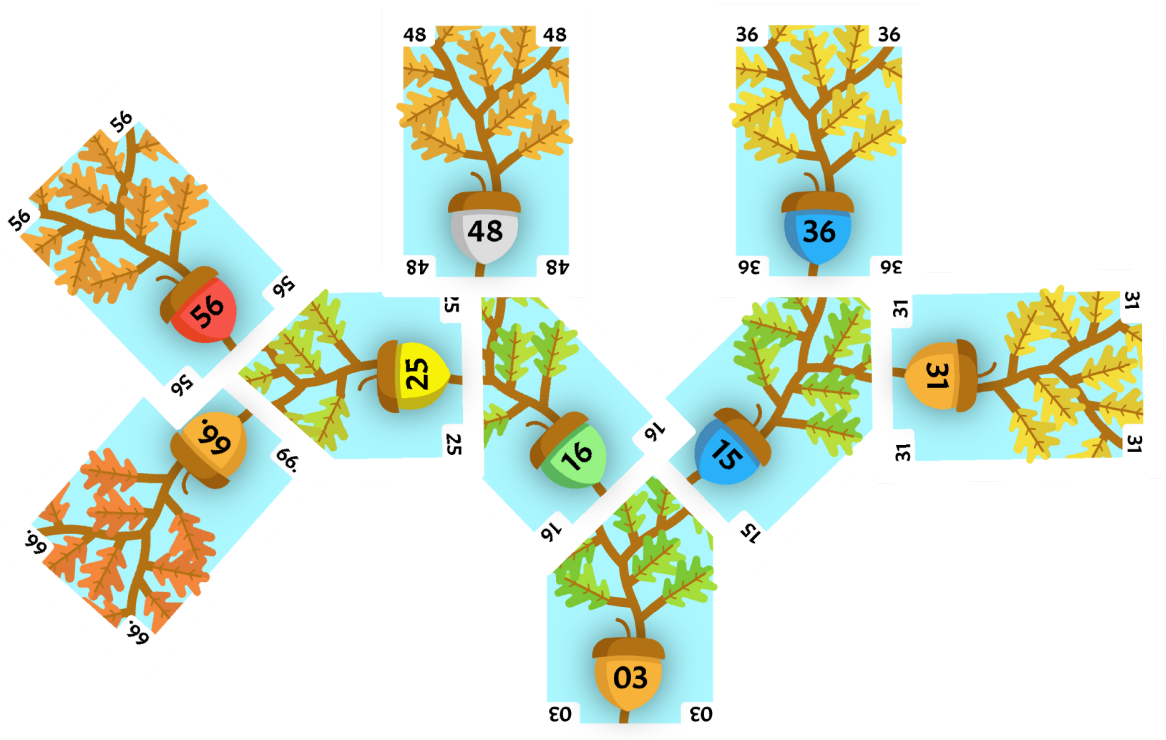

Figure 2) Heap constructed using the Acorn Deck

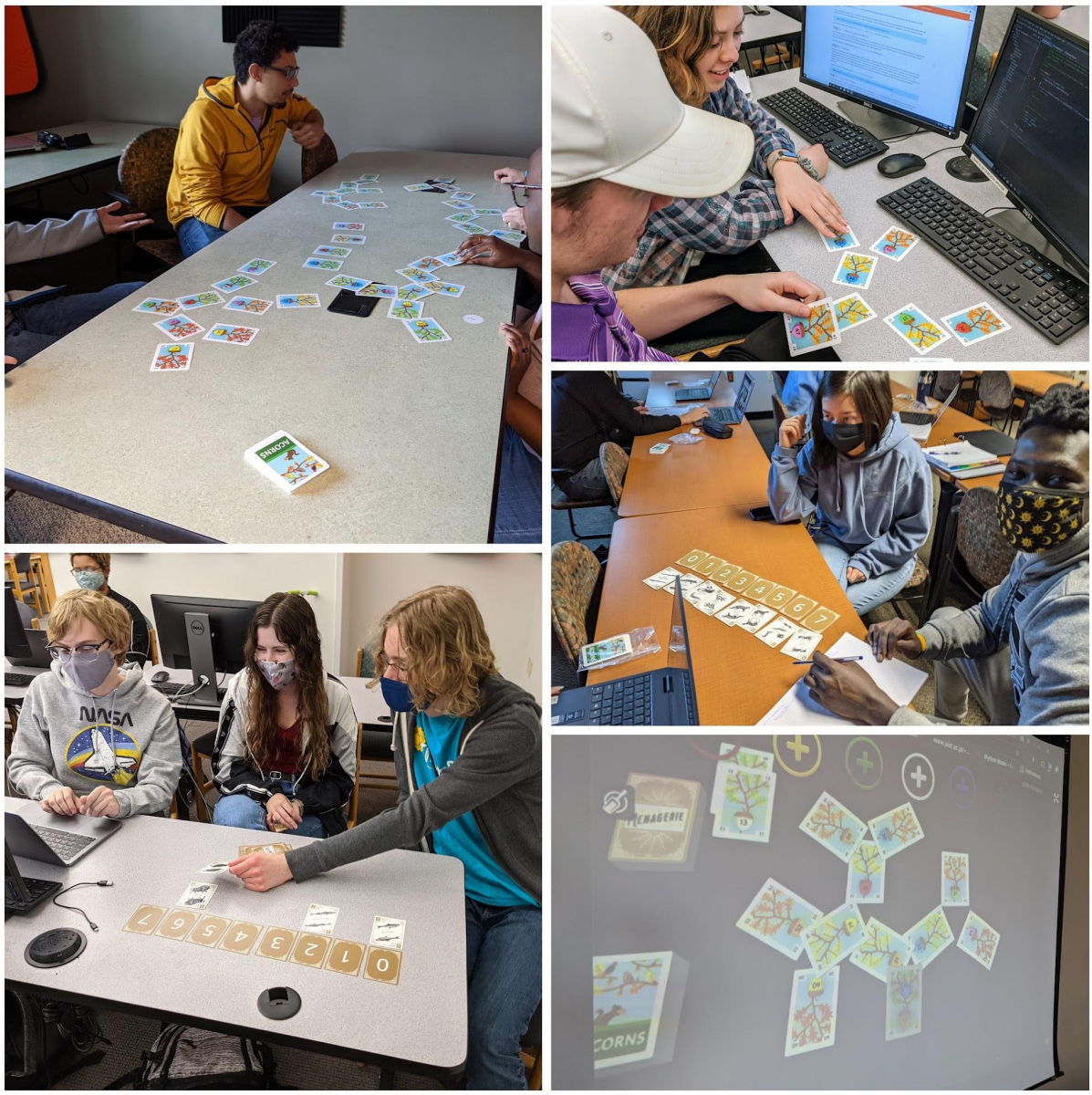

Figure 3) This collage shows the multiple ways this deck has been tested and used in CS2 classrooms at Hendrix College, as exam study aids, lab example manipulatives, in-class games, and teacher-led virtual demonstrations.