	Initial Proposal	
	n-Dimensional Graphing Calculator	CS 4091
	September 13, 2023	Jake Mason & Upmanyu Rohit

# 1 Problem

Consider a real valued function of one variable  $f : \mathbb{R} \rightarrow \mathbb{R}$ . By a graph  $G$  of the function  $f$ , we mean a subset of  $\mathbb{R}^2$ ,

$$G = \{(x, y) \in \mathbb{R} \times \mathbb{R} : y = f(x)\}.$$


There exist many applications for visualizing the graph of single variable functions. Several hand held calculators can graph single variable functions. For example, Texas Instruments has a lineup of graphing calculators including the leading TI-Inspire. There are also online applications such as Desmos and GeoGebra with similar capabilities.

Now consider a real valued function of  $n$  variables  $f : \mathbb{R}^n \rightarrow \mathbb{R}$ . The graph  $G$  of  $f$  is defined similarly to that of single variable functions,

$$G = \{(\mathbf{x}, y) \in \mathbb{R}^n \times \mathbb{R} : y = f(\mathbf{x})\}.$$

However, this graph is a subset of  $\mathbb{R}^{n+1}$ . It is not obvious how one should visualize this graph. A 3 dimensional world offers efficient visualization of two-variable functions at best. There are no well known calculators capable of visualizing a real function of  $n$  variables.

The problem is that functions of  $n$  variables are common in nature. It is hard to find a system where values are only dependent on one variable. We seek an application capable of visualzing the graph of functions of  $n$  variables. Such an application will offer details on functions where previously calculations had to be carried out by hand.

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## 2 Solution

We propose the design of a calculator capable of visualizing the graph of a real valued function of  $n$  variables, where  $n \geq 1$ . Our goal is to first design an application with 2 dimensional and 3 dimensional graphing capabilities. We can then implement functions of  $n$  variables and view them using projections onto 2 or 3 dimensional subspaces. Consider a function of  $n$  variables

$$f : \mathbb{R}^n \rightarrow \mathbb{R}.$$

We can project this function onto the  $x_i, x_j$  plane by setting


$$g : \mathbb{R}^2 \rightarrow \mathbb{R} \quad g(x_i, x_j) = f(0, \dots, x_i, \dots, x_j, \dots, 0)$$

where  $x_i$  and  $x_j$  fall in the  $i^{th}$  and  $j^{th}$  positions respectively. A similar result holds for projecting onto 3 dimensional space. We may also consider projections onto arbitrary planes. A plane in 3 dimensional space can be obtained through the equation

$$ax + by + cz = d$$


with  $a, b, c, d \in \mathbb{R}$ . Projecting a function onto such a plane may involve careful rotation of the coordinate axes.

With the general idea set, we plan to implement this design with a user interface for entering functions and selecting a graph view.

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### 3 Milestones & Tasking

2D Graphing  By Sept. 30	Program Initialization Create window on screen Input functions of 1 variable Store functions of 1 variable Display graph of function Allow translation of graph view
3D Graphing  By Oct. 31	Input functions of 2 variables Store functions of 2 variables Display graph (already using projections) Allow rotation of graph view
nD Graphing  By Nov. 30	Input functions of $n$ variables Store functions of $n$ variables Allow choice of projective axes Allow choice of projective plane Display graph onto projected surface
Extra By Nov. 30	Calculate properties of functions such as max, min, avg Display features of graph view such as range, stretch, axes Allow saving of graphs for later use
Testing	Verify graphs of well known functions
Deployment	Show application to mathematics majors and professors Take feedback and make necessary adjustments Continue support for new product

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## 4 MOSCOW

<b>MUST:</b>	Method for displaying graphs of single variable functions on screen Method for storing functions of $n$ variables Method for displaying projections of $n$ variable functions Method for user to input $n$ variable functions Run at stable 60fps with no warnings/errors
<b>SHOULD:</b>	Parser to allow function input as text Display properties of function such as max, min, avg
<b>COULD:</b>	Run on both Windows and Linux Allow saving of graphs for later use
<b>WOULD:</b>	Parser to allow function input as $\text{\LaTeX}$