Design Study for Project 3: Heated Planet

by

Team 1

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Project 3

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Context

In this project we are expanding on the heated plate and heated earth project by adding new functional and nonfunctional requirements. The functional requirements were expanded to include a tilted axis and an elliptical orbit around a heat source, it's Sun. Nonfunctional requirements include persistence of data as the simulation runs and the ability to retrieve and interpolate from that data when called to do so, greater transparency which will hide the source of result data from the user, improved user experience through an enhanced user interface and architecture best practices including use of design patterns.

The elliptical orbit changes the problem in that the distance from the planet to the heat source also changes even though we can still assume that each point on the planet is the same distance from the heat source. The planet's tilt or obliquity means that the heat source will not always be located directly over the equator at noon and that its proximity to the equator varies as it moves further north and south with a change in seasons which impacts the heat attenuation of different points on the planet. Both of these functional requirements introduce changes to underlying algorithms and increased data resulting from the simulation.

Each simulation will be recorded along with the configuration parameters so that results can be analyzed. Data persistence techniques will be analyzed in terms of cost and benefits where consideration will be given different ranges of persistence where results can be minimally recalculated using interpolation techniques to little or no persistence where the entire simulation is performed from scratch. The source of the underlying calculations must be transparent to the user and only accessible during analysis.

With the added complexity involved with calculations for orbit and tilt, additional configuration parameters, increased amounts of data and transparency to the end user, the user experience must be improved on from earlier iterations of the heated object series of projects. In order to meet these nonfunctional requirements, the team carefully considered the software architecture, introduced design patterns where appropriate to simplify the development, and helped introduce a level of abstraction between the objects performing the simulation and the presentation to the end user.

Research Questions

Item #	Research Question Description
1	What effect did the data-source transparency have on the program? How did it vary with the change in physical factors and simulation settings?
2	What effect did varying the grid spacing have on accuracy, response time and required storage?
3	What effect did the rate of presentation (simulation time step and presentation display rate) have on the user experience?
4	What effect did varying geographic precision have on accuracy, response time and required storage?
5	What effect did varying temporal precision have on accuracy, response time and required storage?
6	What effect did varying the precision have on accuracy, response time and required storage?
7	What effect did seasonality have on results given physical factors (axial tilt, orbital eccentricity) and simulation settings (grid spacing, simulation time step, simulation length)?
8	What are the costs and benefits of using persistence?

9	How long did it take for your simulation to stabilize? How did this depend on the initial conditions?
10	How you would determine the usability of your presentation and controls?

Table 1: Research Questions

Subjects

Subject Name	Subject Description
Computed	The program calculates results given the current configuration of physical factors and simulation settings.
Interpolated	Given that the program has been run with the same physical factors previously, the program will use the stored data and interpolate values since the simulation settings are considered as approximations.

Table 2: Subjects

Experimental Conditions

The study takes place on a virtualized machine that was provided to us by CS 6310 instructors. The virtual machine runs on 64-bit Ubuntu which is a Debian-based Linux operating system. The application is written for the Java 1.6 runtime environment. The virtual machine is configured with 2GB of RAM, dynamically allocated disk space and it runs on a single CPU. Building the program depends on classpath can be done using command in Table 3.

	Build Parameters
`Command`	`cd src/` `javac PlanetSim/Demo.java`
`Where`	`From the root of the project directory`

Table 3: Building the program

The program's execution depends on parameters listed in Table 4.

	Execution Parameters
Command	`java -cp lib/derby.jar:src/ PlanetSim.Demo [-p #] [-g #] [-t #]`
Command line arguments	`-p #:  Indicates the precision of the data being stored.  The value indicates the # of decimal digits to the right of the decimal point.`
	`-g #:  Indicates the percentage of the number of grid cells saved versus the number simulated (geographic precision).  Default is 100%. Value is integer.`
	`-t #:  Indicates The percentage of the number of time periods saved versus the number computed (temporal precision).  Default is 100%. Value is integer.`

Table 4: Execution Parameters

Variables

All dependent and independent variable have been explained in Table 5

Variable Name	Type	Description
precision	independent	Indicates the precision of the data being stored. The value indicates the # of decimal digits to the right of the decimal point. Default is 45. Value is integer.
geographic precision	independent	Indicates the percentage of the number of grid cells saved versus the number simulated (geographic precision). Default is 100%. Value is integer.
temporal precision	independent	Indicates The percentage of the number of time periods saved versus the number computed (temporal accuracy). Default is 100%. Value is integer.
axial tilt	independent	Value of the tilt of the planet in degrees between +/- 180 degrees. Default is +23.44 (toward the Sun) in the northern hemisphere of the summer solstice.
orbital eccentricity	independent	Actual shape of the orbit the planet takes around the Sun. Non negative real number less than one. Default is 0.0167.

grid spacing	independent	The grid size determines the number of cells which represent the areas to calculate the temperature across the earth. Measured in degrees with a default of 15.
simulation time step	independent	This value represents how much simulated time passes between temperature recalculations. Measured in integer increments. Non-negative integer minutes between 1 and 525,960 with a default of 1,440.
simulation length	independent	Amount of time the simulation runs. Non-negative integer representing solar months. Between 1 and 1200. Default is 12 (1 solar year).
presentation display rate	independent	Control the rate at which the presentation is displayed. Refresh / minute using simulation time step. Integer value greater than 0.
accuracy	dependent	Visual interpretation of results. Seasonality, temperature versus sun position
response time	dependent	The amount of time in nanoseconds taken from the time the user clicks to start a simulation or query until the results are returned.
required storage	dependent	Amount of space required to store the results of executing the program for a given configuration.
performance	dependent	Maximum amount of memory in megabytes used during the simulation or query
time to stabilize	dependent	Time required for the earth's temperature to begin to cycle on a daily basis where the initial conditions no longer have an impact based on a visual interpretation of the results.

Table 5: Variables

Metrics

Name	Description	Unit
precision	Number of decimal places	integer
geographic precision	Percentage of the number of grid cells saved versus the number simulated	integer
temporal precision	Percentage of the number of time periods saved versus the number computed	integer

axial tilt	Value of degrees the planet is tilted toward/away from the heat source	float
orbital eccentricity	Value of the degree the planet's orbit deviates from being a circle	float
grid spacing	Value of how to divide the planet into equal parts that is divisible by 180	degrees
simulation time step	How often minutes between 1 and 525,960 to calculate the cell temperature values	integer
simulation length	Number of months the simulation is to run between 1 and 1200	integer
presentation display rate	Control the rate at which the presentation is displayed.	Refresh / minute
accuracy	Visual interpretation of results. Seasonality, temperature vrs sun position	(interpreted)
response time	The amount of time in nanoseconds taken from the time the user clicks to start a simulation or query until the results are returned.	nanoseconds
required storage	Size of file containing data	MB
performance	Maximum amount of memory used.	Bytes
time to stabilize	Duration of the process recorded in seconds.	(interpreted)

Table 6: Metrics of each variable

Variable Summary

#	*Independent Variables*	*Dependent Variables*
1	precision	accuracy, response time, required storage, performance, time to stabilize
2	geographic precision	accuracy, response time, required storage, performance, time to stabilize
3	temporal precision	accuracy, response time, required storage, performance, time to stabilize
4	axial tilt	accuracy, response time, required storage, performance, time to stabilize

5	orbital eccentricity	accuracy, response time, required storage, performance, time to stabilize
6	grid spacing	accuracy, response time, required storage, performance, time to stabilize
7	simulation time step	accuracy, response time, required storage, performance, time to stabilize
8	simulation length	accuracy, response time, required storage, performance, time to stabilize
9	presentation display rate	accuracy, response time, required storage, performance, time to stabilize

Table 7. Independent and Dependent Variables

Methods

Details of method of testing , number of trials, corresponding input variables have been listed in Table 8.

Test #	***Number of trials***	***Description***
1	3	Measure the effect varying precision has on accuracy, response time, required storage, performance and time to stabilize. For a fixed set of physical factors and simulation settings precision values 0, 100, 200, 315 were tested.
2	4	Measure the effect varying geographic precision has on accuracy, response time, required storage, performance and time to stabilize. For a fixed set of physical factors and simulation settings geographic precision values of 25, 50, 75, 100 were tested.
3	4	Measure the effect varying temporal precision has on accuracy, response time, required storage, performance and time to stabilize. For a fixed set of physical factors and simulation settings temporal precision values of 25, 50, 75, 100 were tested.
4	5	Measure the effect varying axial tilt has on accuracy, response time, required storage, performance and time to stabilize. For a fixed set of physical factors and simulation settings axial tilt values of -180, -90, 0, 90, 180 were tested.
5	4	Measure the effect varying orbital eccentricity has on accuracy, response time, required storage, performance and time to stabilize. For a fixed set of physical factors and

		simulation settings axial tilt values of 0, .25, .5, .75 were tested.
6	4	Measure the effect varying grid spacing has on accuracy, response time, required storage, performance and time to stabilize. For a fixed set of physical factors and simulation settings grid spacing values of 15, 60, 90, 180 were tested.
7	5	Measure the effect varying simulation time step has on accuracy, response time, required storage, performance and time to stabilize. For a fixed set of physical factors and simulation settings varying simulation time step values of 1, 5000, 10000, 100000, 525600 were tested.
8	4	Measure the effect varying simulation length has on accuracy, response time, required storage, performance and time to stabilize. For a fixed set of physical factors and simulation settings simulation length values of 1, 100, 500, 1200 were tested.
9	4	Measure the effect varying presentation display rate has on accuracy, response time, required storage, performance and time to stabilize. For a fixed set of physical factors and simulation settings presentation display rate values of 1, 5, 10, 20 were tested.
10	4	Measure the effect of geographical precision on response time, storage, and performance when the query date range is within an existing simulation and outside the existing simulation. For a fixed set of factors for the query the geographical precision values of 0, 25, 50, and 100 were tested.
11	4	Measure the effect of temporal precision on response time, storage, and performance when the query date range is within an existing simulation and outside the existing simulation. For a fixed set of factors for the query the temporal precision values of 0, 25, 50, and 100 were tested.

Table 8. Methods

<u>Program invocations with arguments:</u>

Program invocation can be referred to table 2. Program arguments syntax is located in table 4, with the values used for each test case listed in table 8.

Significant digits:

The program uses recommended data types and default values as specified. The program does allow the user to change values for precision, temporal precision and geographic precision; however, no additional rounding takes place other than from the Derby database. No additional purposeful rounding of significant digits has been coded for.

Analysis Techniques

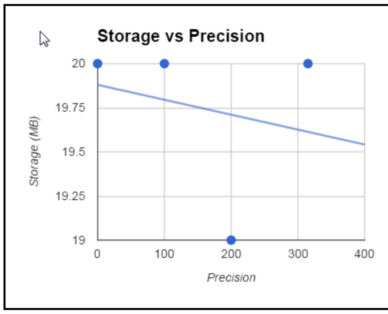
We will be using Excel and Google to conduct analysis for the data in this project. Using charts such as bar and line as well as tables to illustrate the relevant data points. We carefully considered what we were testing and came up with a series of research questions. For each question, we decided on which variables we could study and which were dependent versus independent. Once we gained a complete understanding of the research questions and what we can control and measure, we developed a series of tests that would help us with our analysis. The approach we took was to vary the dependent variable against a fixed set of program configuration and measure the dependent variable results. Because of resource limitations we ran each test looking for anomalies of expected behavior. If an anomaly occurred we reran the test to ensure the result was not from user error or resource contention.

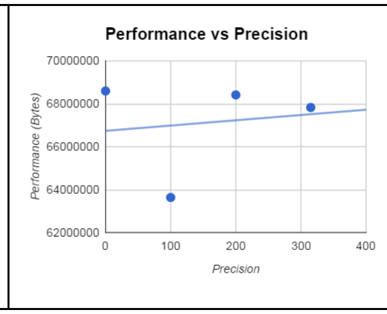
Results

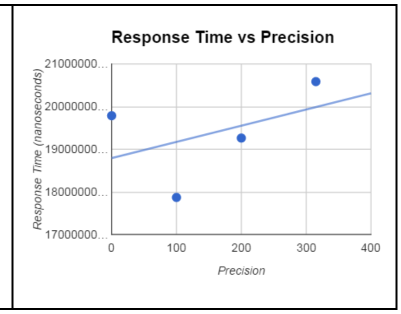
Test 1

Result Data

Simulation Type:	Simulation										
Independent Var:	Precision										
Storage	Performance	Response Time	**Precision**	Geographic Precision	Temporal Precision	Axial Tilt	Orbital Eccentricity	Simulation Time Step	Grid Spacing	Simulation Length	Presentation Display Rate
20	68598120	197865372766	0	100	100	23.44	0.167	1440	15	12	5
20	63635872	178696875546	100	100	100	23.44	0.167	1440	15	12	5
19	68415464	192625076675	200	100	100	23.44	0.167	1440	15	12	5
20	67830448	205860783152	315	100	100	23.44	0.167	1440	15	12	5



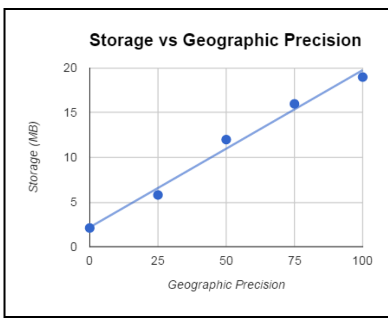


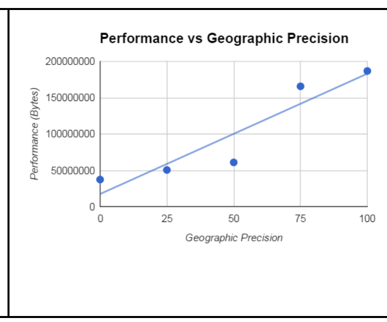


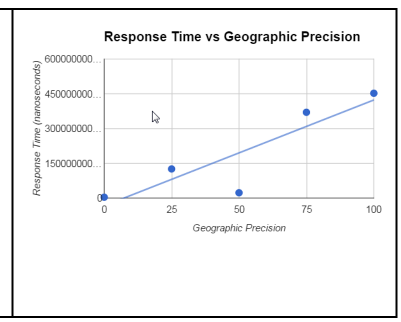
Test 2

Result Data

Simulation Type:	Simulation										
Independent Var:	Geographic Precision										
Storage	Performance	Response Time	Precision	**Geographic Precision**	Temporal Precision	Axial Tilt	Orbital Eccentricity	Simulation Time Step	Grid Spacing	Simulation Length	Presentation Display Rate
2.1	37269952	4109227188	45	0	100	23.44	0.167	1440	15	12	5
5.8	50455493	125940109138	45	25	100	23.44	0.167	1440	15	12	5
12	60905168	23313350961	45	50	100	23.44	0.167	1440	15	12	5
16	165674552	370313667899	45	75	100	23.44	0.167	1440	15	12	5
19	186828416	452518436636	45	100	100	23.44	0.167	1440	15	12	5



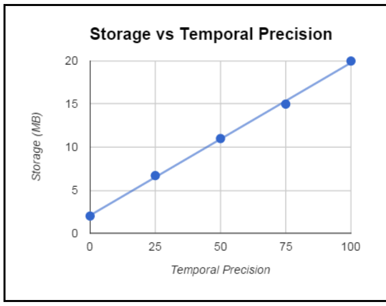


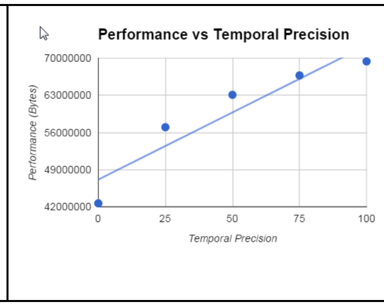


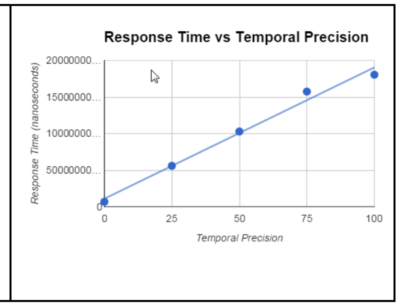
Test 3

Result Data

Simulation Type:	Simulation										
Independent Var	Temporal Precision										
Storage	Performance	Response Time	Precision	Geographic Precision	**Temporal Precision**	Axial Tilt	Orbital Eccentricity	Simulation Time Step	Grid Spacing	Simulation Length	Presentation Display Rate
2	42664072	6778380408	45	100	0	23.44	0.167	1440	15	12	5
6.7	56992264	55877254279	45	100	25	23.44	0.167	1440	15	12	5
11	63087264	102816915448	45	100	50	23.44	0.167	1440	15	12	5
15	66740328	157404893724	45	100	75	23.44	0.167	1440	15	12	5
20	69378600	180434419460	45	100	100	23.44	0.167	1440	15	12	5



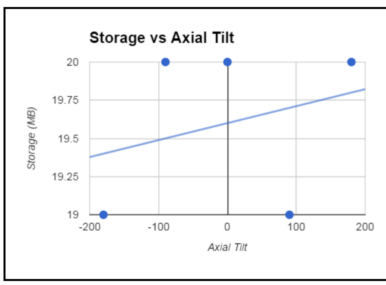


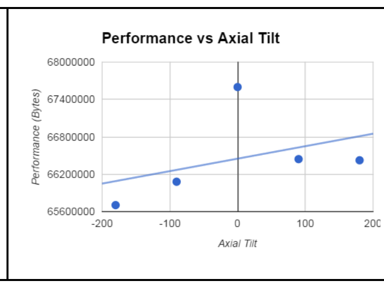


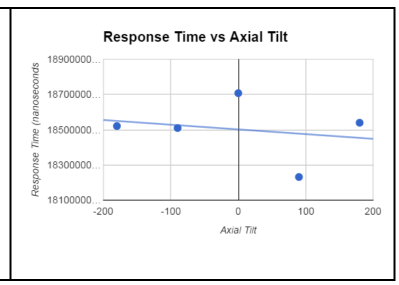
Test 4

Result Data

Simulation Type:	Simulation										
Independent Var:	Axial Tilt										
Storage	Performance	Response Time	Precision	Geographic Precision	Temporal Precision	**Axial Tilt**	Orbital Eccentricity	Simulation Time Step	Grid Spacing	Simulation Length	Presentation Display Rate
19	65704904	185206110591	45	100	100	-180	0.167	1440	15	12	5
20	66079656	185096141888	45	100	100	-90	0.167	1440	15	12	5
20	67598472	187075303258	45	100	100	0	0.167	1440	15	12	5
19	66442544	182314789788	45	100	100	90	0.167	1440	15	12	5
20	66424008	185395226877	45	100	100	180	0.167	1440	15	12	5



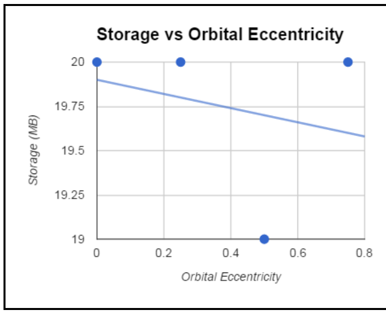


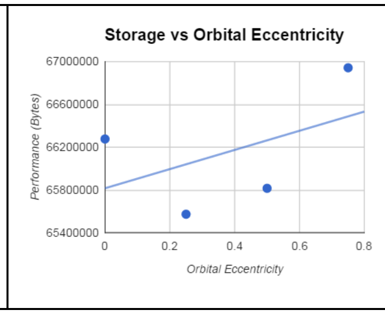


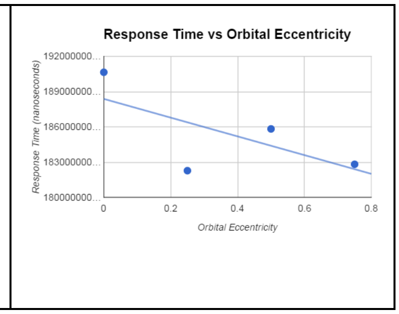
Test 5

Result Data

Simulation Type:	Simulation										
Independent Var:	Orbital Eccentricity										
Storage	Performance	Response Time	Precision	Geographic Precision	Temporal Precision	Axial Tilt	**Orbital Eccentricity**	Simulation Time Step	Grid Spacing	Simulation Length	Presentation Display Rate
20	66276480	190646344634	45	100	100	23.44	0	1440	15	12	5
20	65573104	182272895270	45	100	100	23.44	0.25	1440	15	12	5
19	65815472	185825759157	45	100	100	23.44	0.5	1440	15	12	5
20	66942376	182816872658	45	100	100	23.44	0.75	1440	15	12	5



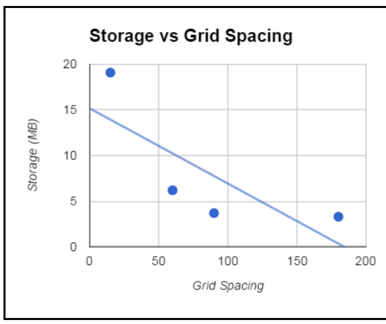


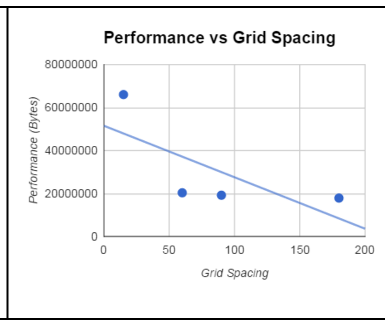


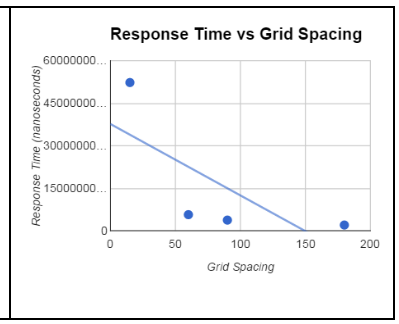
Test 6

Result Data

Simulation Type:	Simulation										
Independent Var:	Grid Spacing										
Storage	Performance	Response Time	Precision	Geographic Precision	Temporal Precision	Axial Tilt	Orbital Eccentricity	Simulation Time Step	**Grid Spacing**	Simulation Length	Presentation Display Rate
19.1	66061184	522867542482	45	100	100	23.44	0.167	1440	15	12	5
6.2	20352584	56777108137	45	100	100	23.44	0.167	1440	60	12	5
3.7	19225520	37633269645	45	100	100	23.44	0.167	1440	90	12	5
3.3	17901088	20251996150	45	100	100	23.44	0.167	1440	180	12	5



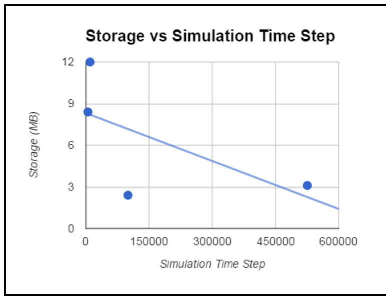


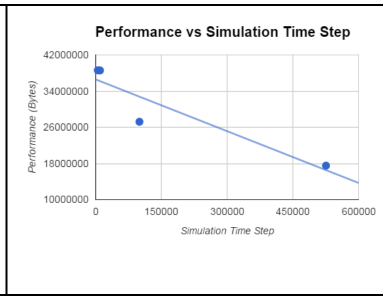


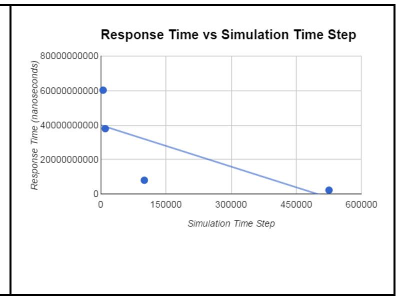
Test 7

Result Data

Simulation Type:	Simulation										
Independent Var:	Simulation Time Step										
Storage	Performance	Response Time	Precision	Geographic Precision	Temporal Precision	Axial Tilt	Orbital Eccentricity	**Simulation Time Step**	Grid Spacing	Simulation Length	Presentation Display Rate
8.4	38581056	60234309186	45	100	100	23.44	0.167	5000	15	12	5
12	38556424	37895295589	45	100	100	23.44	0.167	10000	15	12	5
2.4	27214640	7949629515	45	100	100	23.44	0.167	100000	15	12	5
3.1	17521968	2185310099	45	100	100	23.44	0.167	525600	15	12	5



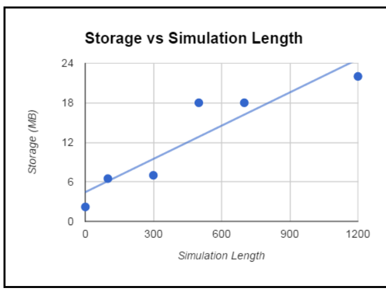


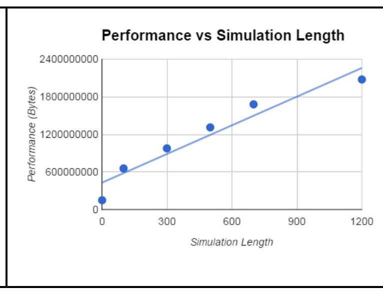


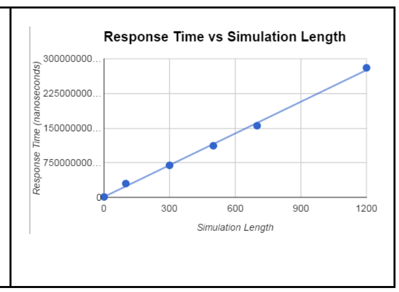
Test 8

Result Data

Simulation Type:	Simulation										
Independent Var	Simulation Length										
Storage	Performance	Response Time	Precision	Geographic Precision	Temporal Precision	Axial Tilt	Orbital Eccentricity	Simulation Time Step	Grid Spacing	**Simulation Length**	Presentation Display Rate
2.2	148912880	1053207593	45	10	10	23.44	0.167	1440	15	1	5
6.5	656729088	29935701729	45	10	10	23.44	0.167	1440	15	100	5
7	976527312	69385472669	45	10	10	23.44	0.167	1440	15	300	5
18	1311083552	111757726128	45	10	10	23.44	0.167	1440	15	500	5
18	1679405504	155038310523	45	10	10	23.44	0.167	1440	15	700	5
22	2075878744	280292880772	45	10	10	23.44	0.167	1440	15	1200	5



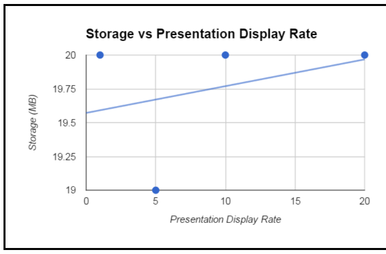


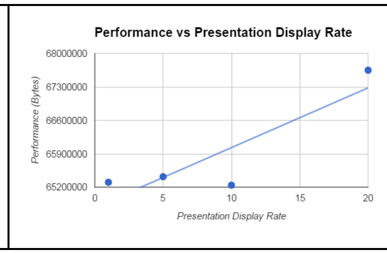


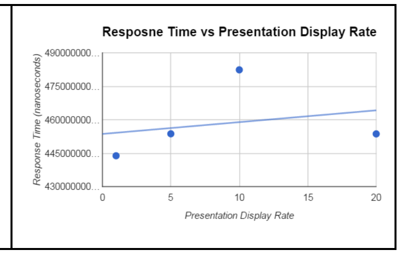
Test 9

Result Data

Simulation Type:	Simulation											
Independent Var:	Presentation Display Rate											
Storage	Performance	Response Time	Precision	Geographic Precision	Temporal Precision	Axial Tilt	Orbital Eccentricity	Simulation Time Step	Grid Spacing	Simulation Length	**Presentation Display Rate**
20	65303928	443844898955	45	100	100	23.44	0.167	1440	15	12	1
19	65420739	453695373731	45	100	100	23.44	0.167	1440	15	12	5
20	65243104	482364374228	45	100	100	23.44	0.167	1440	15	12	10
20	67649304	453649125020	45	100	100	23.44	0.167	1440	15	12	20



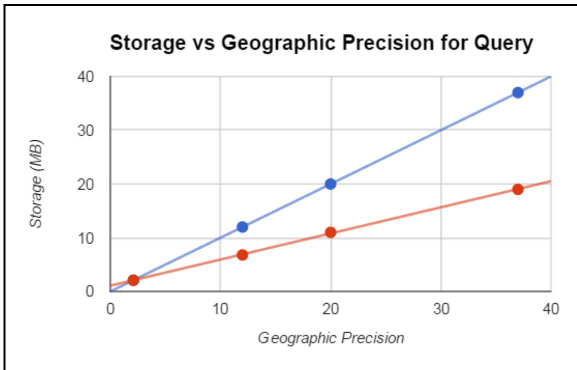


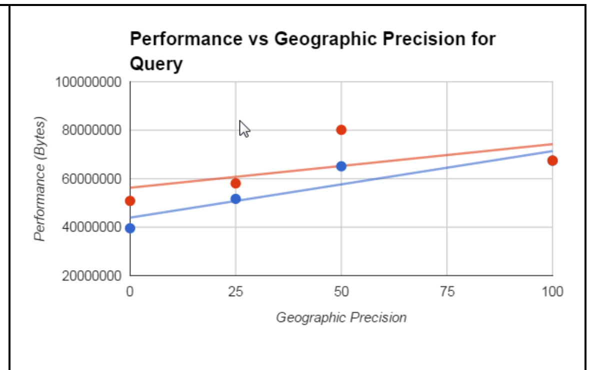


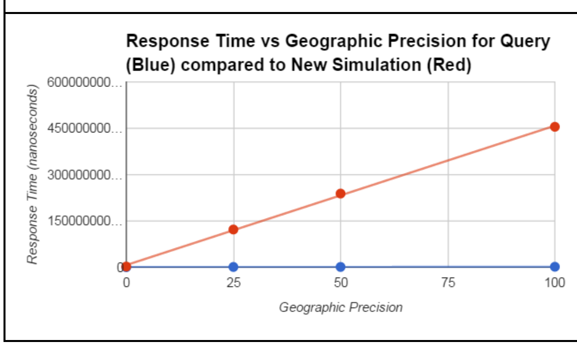
Test 10

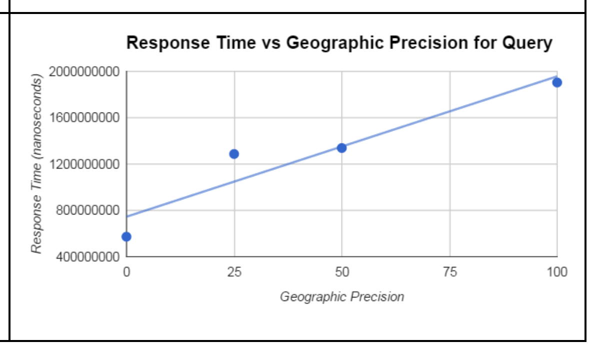
Result Data

	Run Simulation with these settings							
Axial Tilt	Orbital Eccentricity	Simulation Time Step	Grid Spacing	Simulation Length	Presentation Display Rate			
23.44	0.167	1440	15	12	5			
Simulation Type:	Query							
Independent Var:	Geographic Precision							
Storage	Performance	Response Time	Precision	Geographic Precision	Temporal Precision	Start Date	End Date	Bounds (N,S,E,W)
2.1	36035032	4054822772	45	0	100	simulation info		
2.1	39549728	572557273				1/4/2014	2/4/2014	All
2.1	50844856	2608491979				12/1/2014	1/1/2015	All
6.8	50878832	127683167322	45	25	100	simulation info		
6.8	51674024	1286798643				1/4/2014	2/4/2014	All
12	58084424	122460030221				12/1/2014	1/1/2015	All
11	60393272	232776165468	45	50	100	simulation info		
11	65120552	1338355903				1/4/2014	2/4/2014	All
20	80146720	238798413447				12/1/2014	1/1/2015	All
19	68076176	506212101683	45	100	100	simulation info		
19	67447408	1903939136				1/4/2014	2/4/2014	All
37	67488328	454964459921				12/1/2014	1/1/2015	All





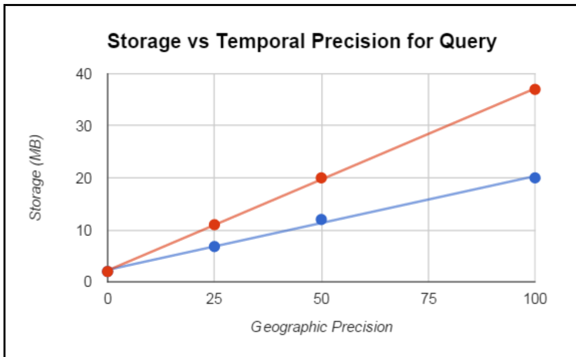


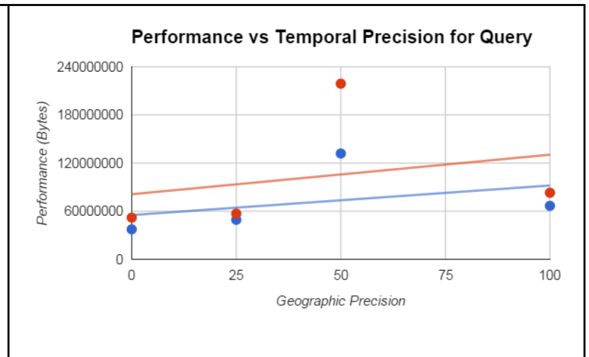


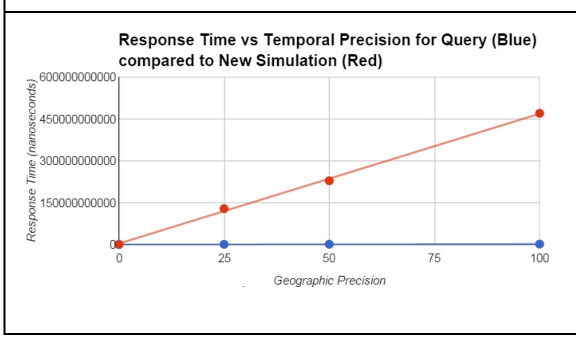
Test 11

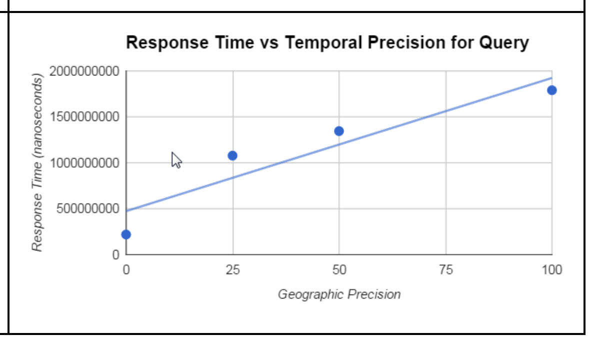
Result Data

		Run Simulation with these settings						
Axial Tilt	Orbital Eccentricity	Simulation Time Step	Grid Spacing	Simulation Length	Presentation Display Rate			
23.44	0.167	1440	15	12	5			
Simulation Type:	Query							
Independent Var:	Geographic Precision							
Storage	Performance	Response Time	Precision	Geographic Precision	Temporal Precision	Start Date	End Date	Bounds (N,S,E,W)
2	29623136	1891899897	45	100	0	simulation info		
2	37413936	219262876				1/4/2014	2/4/2014	All
2	51989176	946078732				12/1/2014	1/1/2015	All
6.8	49635208	128788786091	45	100	25	simulation info		
6.8	49329296	1078044066				1/4/2014	2/4/2014	All
11	56991104	128816111300				12/1/2014	1/1/2015	All
12	125656048	236528735003	45	100	50	simulation info		
12	131913464	1344954006				1/4/2014	2/4/2014	All
20	218902544	228880319641				12/1/2014	1/1/2015	All
19	67277200	455305267652	45	100	100	simulation info		
20	66692384	1789878508				1/4/2014	2/4/2014	All
37	82992288	470514620418				12/1/2014	1/1/2015	All









Discussion

After conducting the experiments and analyzing the results, we found that most of our initial expectations about results held true. There were some research questions that were more easily answered with the data and charts although we did have to rely on empirical data to answer a couple. Data persistence and transparency were both easy to study and understand as the size of the database grew in a linear fashion as was expected when tests that produced more data were executed. When we were able to use existing data and interpolate missing data points, the response time dropped significantly. We did encounter one phenomena with respect to the database size. Test #7, resulted in an unexpected fluctuation in database size where higher simulation time step values resulted in larger database sizes than smaller simulation time step values. Upon examination of data saved to the database it was concluded the actual number of values saved was as expected, the anomaly was solely exhibited in disk space used. This anomaly was attributed to one of two possibilities. One may be the way we were measuring the database size (including log files) or the other possibly a data management feature of Derby's database that we are not familiar with. Accuracy measurements were done by conducting a visual inspection of the presentation which was a much more subjective analysis technique. Since we are all familiar with the domain model and expectations for what we should expect there is the possibility that a bias was unintentionally introduced in the results. The time to stabilize was also gauged by visual inspection although results were convincing in that any initial conditions seemed to be overcome as soon as the program was able to conduct the simulation for a period greater than or equal to a day.

The team members all executed tests using the same virtual environment; however, we did experience differences that could have been introduced by the host environment or by inadvertent changes within individual local environments which could be overcome by conducting the experiments using a shared server. The study process could also be improved by separating the time it takes to develop algorithms and domain analysis from the development period since this typically leaves less time for the analysis and study itself and few opportunities to make adjustments from preliminary results. We included an adaptability section for possible future enhancements that would also help improve the study process.

With respect to scaling, we observed that response time increased significantly as the amount of data increased. Multiple team members were unable to conduct initial tests using the solar months dependent variable as once we reached values of 600-700 the virtual environment memory ran low and raised out of memory exceptions.

The configuration that is chosen to run depends on many factors and may be determined if you are analyzing something specifically similar to what was conducted by the experiments. If you are trying to get a good general depiction of what a planet in motion around a heat source looks like we recommend the following configuration.

Parameter	Value	Description
Geographic Precision	50	A value of 50% produces the most optimal amount of data that limits the amount of storage and helps performance since missing cells can be calculated using the average of its surround neighbors.
Simulation Time Step	1440	This value produces simulation representation that is at the same point so that the results can be

		compared without trying to understand other influencing factors.
Solar Months	> 12	In order to see the simulation run through a complete orbital cycle, the value should be greater than 12 solar months (1 year).
Grid Spacing	10 or 15	In order to better see the effects of seasonality, the grid spacing should remain small.
Other parameters	Default	All other parameters not listed above should be set to their default values for the best representation.

Table 9: Recommended Configuration

Usability:

The user of this program will be conducting a series of tests where they make changes to the dependent variables, run the program and record the independent variable results. The user interface is designed to enable the user to configure appropriate operating parameters and use controls for starting, stopping, pausing, resuming and querying the program. The test does require that the user change some of the invocation arguments which must be done when starting the program through the command line or using a design environment like Eclipse.

In order to improve usability, it would be helpful if the command line arguments were added to the user interface where the user could simply pick his or her configuration. The user interface not only focuses on both inputs and controls, but also on visual presentation. The GUI graphically depicts the change in temperature as the planet rotates, which is helpful but doesn't provide much detail. A nice enhancement may be to log results or provide charts that would help the user see the actual values fluctuate. A scale on the graphic for both grid spacing and temperature color would also be helpful. In order to improve the usability, it would be helpful to conduct a study with the user community to gauge their reaction and receive feedback on the design.

<u>Adaptability:</u>

Name	Description	Type
CDB	System should use a centralized database common to all users. The DAO implementation can be interchanged with a new DAO targeting the CDB. The abstract factory utilized by the application facilitates changing the DAO to the new implementation. No other changes would be necessary.	functional
Planet Configuration	User should be able to specify planet circumference, aldebo, emissivity, major axis, solar year length, and solar power per meter (at source) to simulate more diverse planets. The simulation supports these values as inputs, and they are coded in at the controller level. Inputs can be added and passed to the controller to replace the coded values. Also, the new parameters should be added to the simulation persistence object and possibly the query interface.	functional
Alternate Visualization	The need may arise for an alternate visualization, such as a chart. A new PresentationMethod can be implemented and utilized by the MasterController with no changes to threading or the simulation. There may be GUI changes necessary depending on the choice of visualization.	functional
Simulate on Server	System should use a central server to execute the simulation, requiring less processing power per client. Two approaches are available. A new SimulationMethod can be implemented that makes a request to the server for the simulation and returns the result, requiring no other changes. Preferably, the SimulationController can be modified to open a connection with the server and communicate requests/results over a constant connection. Neither method would require changes to the presentation or threading.	functional
Faster Response Time	Response time should be reduced by improving database response time. The can be committed asynchronously to the simulation and presentation, and therefore could be managed on its own thread and improve simulation response time.	quality

Accuracy	A more accurate simulation algorithm may be discovered. This can be accomplished by implementing a new SimulationMethod containing the new algorithm that will be utilized by the SimulationController. No other changes would be necessary.	quality

Table 10: Adaptability

Conclusions

Item #	Research Question Answer
1	Response time decreased significantly when a result could be read from a database rather than executing a new simulation. The user on the query UI is not concerned with the source of the data and only sees the benefit in response time. The decreased response time is directly related to the geographic and temporal precision. Higher geographic and temporal precision values result in more data being persisted and thus less work to be done if a result is found.
2	Response time and storage drastically decreased from 15 to 60 degrees grid spacing, and further decreased inversely to grid spacing. The team expected this behavior as a larger grid spacing results in fewer grid cells to process and store. Larger grid spacing is less accurate than having a finer grid. This especially affects querying for longitude and latitude where the requested location may fall within a large cell.
3	Varying presentation display rate had negligible effect on response time, resulting in similar user experience.
4	Storage and response time increased linearly with geographic precision. The team expected this behavior as increasing the geographic precision increases the number of grid cells persisted, thus increasing storage and impacting response time with additional database calls. Lower geographic precision will negatively impact accuracy on queries of existing simulations due to interpolation being necessary to complete missing data points.
5	Storage and response time increased linearly with temporal precision. The team expected this behavior as increasing the temporal precision increases

	the number of simulation results persisted, thus increasing storage and impacting response time with additional database calls. Accuracy is not affected because missing results are simulated using the previous simulation as a starting point.
6	Storage and response time remained consistent over variation of precision. The team expected this behavior due to the database schema allocating the necessary space for the decimal regardless of how it was rounded. Had a new database been created or a flat file been used, the team expects to see a more drastic increase in storage. Accuracy is very slightly decreased on queries of existing simulations due to rounding before storing in the database.
7	The team expected to see the effects of seasonality due to orbit and tilt, but the simulation did not reflect a measurable variation in temperatures that would result from seasonality either visually or by analysis of the data. The team theorizes that a smaller simulation time step and finer grid spacing would make seasonality more evident.
8	Persistence comes with a large cost in response time which is evident in tests 2 (geographic precision) and 3 (temporal precision) where the amount of information persisted varied. There are also the storage costs in persisting the data to disk, along with the cost associated to maintaining the code for data access and migrating the database in the case of an enhancement. The response time will decrease, however, when a result has already been calculated and can simply be retrieved. This is especially true for queries around specific date ranges, where a system without persistence would need to simulate up to the start date before having any relevant data.
9	Based on the visual representation of the planet the stabilization tended to occur quickly if the time step was set to a day.
10	The application usability was very straightforward. Simple controls were implemented and validation occurred as expected. The graphical visualization was helpful in displaying the information in a useful way. Additional responses to the usability are included under the Usability section.

Table 11: Conclusions

Citations

[1] Gamma, Erich Helm, Richard, Johnson, Ralph and Vlissides, John. Design Patterns: Addison-Wesley, 1995.