AgentSheets®: an Interactive Simulation Environment with End-User Programmable Agents

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Abstract

Current Information Technology is mostly focused on *accessing* information and provides little support for *processing* information. An exponentially growing amount of information becomes increasingly unmanageable with today's information technology approaches. Through web portals, emails, chat rooms, and news lists all kinds of information can be accessed everywhere, all the time. Often embedded in rapidly flashing animations the information glut is fighting for our attention and we are fighting to locate relevant information. The ability to access information is a crucial first step but now we need to explore new means of *processing* information. How can we keep up with frequently updated website content and setup autonomous computation helping us *to process* that information?

End-user programmable agents are a means to give people autonomous information-processing power. Simulation is a form of information processing. Agents can be used to build interactive simulations. AgentSheets® is an agent-based simulation-authoring tool that allows end-users to build interactive simulations and publish them as Java applets on the web. Interactive simulations can help people to explore complex issues and communicate them to other people effectively. Interactive simulations are more engaging than static text, images and even video. Moreover, people can define the behavior of end-user programmable agents to access existing information such as stock ticker symbols and to process that information by analyzing and synthesizing it.

Introduction

With the dawn of the new millennium we are reflecting on the relatively short history of the information age. Yes, we have come a long way from the early beginnings. The Internet has matured from being a peculiar playground of a handful of researchers to a rapidly growing network connecting people, resources and services all over the planet. The rate of adoption is truly astonishing. In just 7 years the Internet has attained a market share of 25%. It took telephone 35 years to achieve the same penetration.

In a technological context, reflection is often accompanied by prediction. What is next with information technology? What will we be able to do with technology, what will technology do to us? On an analytical level we have tools such as Moore's law helping us to capture technological growth as mathematical functions. According to Moore's law the speed of computer chips doubles every 18 months. Despite earlier calls for caution this has been true for many years. Even growth limitations attributed to physical constraints such as molecular limitations regularly have been overcome with new innovations. Maybe as soon as this or the next year we will see the first consumer PCs featuring 1 Giga Hertz clocked CPUs. Soon thereafter we will forget that there ever were CPUs operating at non-Giga Hertz speeds. Mega Hertz measurements will no longer be associated with computers at all. Instead all we will associate with Mega Hertz measure will the frequency of FM radio stations.

Another kind of growth equally astonishing as the growth of computing speed is the growth of information spaces. Just like the speed of CPUs the number of websites on the

Internet is growing exponentially. Since we are running out of valid internet IP numbers, soon we need to replace the current internet addressing scheme with a new one capable to deal with this kind of growth. Plotting the amount of information accessible via the Internet and the computing speed versus time we cannot react any other way than being genuinely impressed with information technology. No other technology ever has changed our lives so rapidly, so profoundly.

How do we benefit from increasing information volume and computing speed? A loaded question to be sure. It is not clear what the exact shape of the curve would be if we were to plot the average Intelligence Quotient (IQ) or – if there would be such as thing – the Creativity Quotient over time. My fear is that IQ and CQ would look remarkably flat next to CPU speed and information volume. Maybe this is not terribly surprising but it still raises a number of essential issues. Just how it is possible that with more information accessible and with more computation power available we still fail to experience any kind of profound impact on the qualitative aspects of live such as education? The average degree of understanding of the world (science, politics, nature, etc.) appears not to have changed much despite the fact that most answers to complex questions may be just one web search away.

ECommerce has become the most celebrated application of the Internet. Jeff Bezos, CEO of Amazon.com was just selected to be “1999 Person of the Year” by Time magazine for his pioneering success with eCommerce. I do not wish to attack these efforts in any way – I order most of my books from Amazon – but really hope that as a society we can push the internet beyond the aspiration of turning the web into a gigantic virtual shopping mall. Despite the rapid, again exponential, growth of shopping transaction on the web it is unlikely that in the end more people are reading books. There simply have to be information technology applications that have the potential to truly enrich life and not just to serve as a commodity. Today’s Internet killer apps (email, and eCommerce) push old types of content such as text, images and videos, through new media. What kind of other content types could there be and how can people use them to do what?

In the remainder of this paper some scenarios are presented in which information technology is used as medium distributing *interactive* content. Interactive content such as simulations cannot be captured on a static, paper-based, medium. By now, the computational power of personal computers has reached the necessary levels to run sophisticated simulations that would have required a supercomputer only a couple of years ago. Using technologies such as Java and Flash, interactive content can be embedded in web pages and made accessible to everybody on the planet with a web browser.

By now the idea of featuring interactive content on the Internet is not all that new anymore. However, the applications of interactive content discussed here are different in the sense that people who are not programmers or web designers have built this interactive content. The quest is the exploration of new tools that will enable computer end-users to build interactive content very much in the same spirit as tools – now called word processors – have enabled end-users to build static content on their computers. The specific tool discussed here called AgentSheets is only one instance of a more general framework of end-user tools to author interactive content. No detailed description of AgentSheets can be given here. Following a quick overview of the AgentSheets authoring tool is a description of how people have used AgentSheets to build simulations which, in turn, have been used to communicate complex ideas or to further their own understanding in ways impossible with static media.

AgentSheets: A Simulation Authoring Tool

Combining Java authoring, end-user programmable agents and spreadsheet technology, AgentSheets [Repenning and Sumner 1995] [Repenning, et al. 1998] (http://www.agentsheets.com) is an authoring tool that empowers casual computer users with no formal programming training to build and publish web-based interactive simulation.

Figure 1. AgentSheets combines Agent, Spreadsheet and Java Authoring technology

AgentSheets enables users to create such simulations, using its end-user programming language Visual AgenTalk® (VAT). Users design agents' looks by drawing icons and create agents' behaviors by composing VAT conditions and actions from command palettes into rules. Conditions and actions allow agents to do a variety of operations including:

- compute spreadsheet-like formulas
- react to mouse clicks and key strokes
- sense other agents
- send messages to agents
- play sampled sounds and MIDI instruments
- speak
- gather information from web pages

Visual AgenTalk employs a new approach to end-user programming called Tactile Programming. Tactile Programming primitives and programs not only have enhanced visual representations to help program readability, but also have interactive interfaces to assist with program writability. Tactile Programming is well suited for collaborative use since it eases program *composition*, *comprehension* and *sharing* [Repenning and Ambach 1996] of behaviors.

A wide spectrum of users, ranging from elementary school students with no programming background to scientists, have used AgentSheets and VAT to create interactive simulations and games in a variety of disciplines including computer science, environmental design, fine art, robotics, music, history, and biology. In an elementary school science class, students created ecosystem simulations to explore food webs and sustainability issues. In a high school history class, students created social and historical simulations. Scientists working with NASA created simulations of E.coli bacteria fermenting in zero gravity.

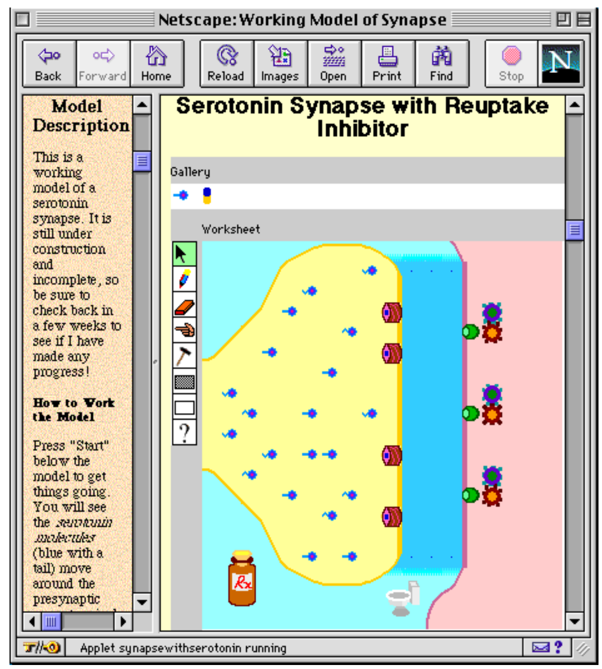

Figure 2: SimProzac: Simulation running in a webpage explaining how Serotonin works in the Synapse and how Antidepressants affect the system.

Figure 2 above shows an interactive simulation explaining the effects of Prozac to patients by modeling a serotonin synapse in the brain. The simulation was built by a psychiatrist for his patients. For this particular simulation, a suite of agents (Table 1) was created by specifying their look and their behavior using the Visual AgenTalk language. Figure 3 illustrates two VAT rules from the behavior of the Serotonin molecule defining animation and interaction with membranes.

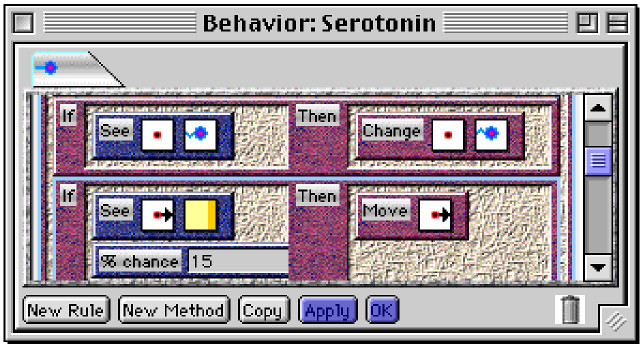

Figure 3: Part of the serotonin behavior which specifies that if the serotonin looks like , it will change to , or with 15% chance if the serotonin sees a membrane to its right, it will move to the right.

The specific point of building the SimProzac simulation was to communicate complex chemical interactions to patients. The web serves as an ideal platform to harness the communicative power of interactive simulations such as SimProzac. Entire AgentSheets simulations can be exported as Java applets and JavaBeans, using the Ristretto™ Agent-to-Java-Byte-Code generator [Repenning and Ioannidou 1997]. This allows simulations to be published on the web making them accessible to a larger community of users. Using Ristretto™ the serotonin simulation was turned into a Java applet (Figure 2).

Using Simulations in Lifelong Learning

AgentSheets appeals to an unusually wide range of users. This general applicability makes AgentSheets an ideal tool for lifelong learning including K-12 education, University level education and workplace training [Gina Cherry, et al. 1999]. Justin Martin [Martin 1998] put the market potential of lifelong learning into numbers: "The Knowledge-based economy is in full bloom. America's investment in lifelong learning—everything from teaching kids in the schools to training adults in the work force—runs to $665 billion a year, more than is spent on national defense."

The following sections provide a sense of the applicability of AgentSheets by presenting example projects.

Elementary Schools: EcoWorlds

Current reform efforts in science education emphasize constructivist pedagogies - approaches that place students at the center of the sense-making process and suggest that students learn by actively building their own understanding of a topic. One promising approach to meaningful learning and robust understanding of science centers on the creation and use of computer simulations as representations of how and why things work [Papert and Harel 1993]. Activities with simulations have the potential to help children organize, develop, test, and refine their ideas about science.

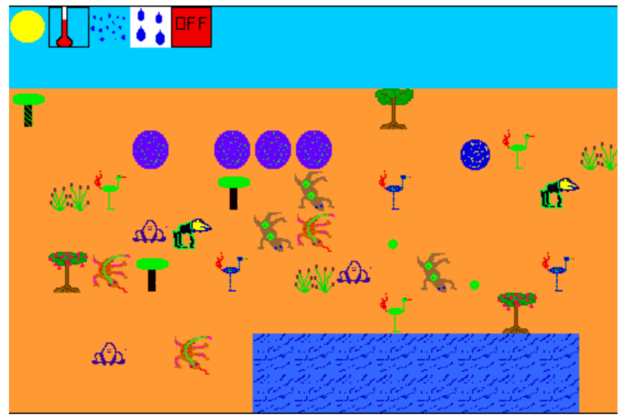

Figure 4. A simulation world populated with animal agents designed by kids

The Science Theater/Teatro de Ciencias (sTc) project has developed a number of activities with simulations for elementary school students [Rader, et al. 1998]. The EcoWorlds curriculum for 4th and 5th graders focuses on a number of content areas, including characteristics of organisms, structure and function in living systems, populations and ecosystems, and diversity and adaptations of organisms. The EcoWorlds unit addresses these issues by having students work in small groups to create computer simulations of ecosystems in different environments such as the arctic or a desert. Activities with simulations are integrated into a curriculum, which incorporates hands-on activities, research activities, and class discussions.

In the Science Theater activity kids collaboratively design animals and exchange them through the Behavior Exchange. The Behavior Exchange is a web-based repository of agents allowing AgentSheets users to share useful agents with each other (http://www.agentsheests.com/behavior-exchange.html)

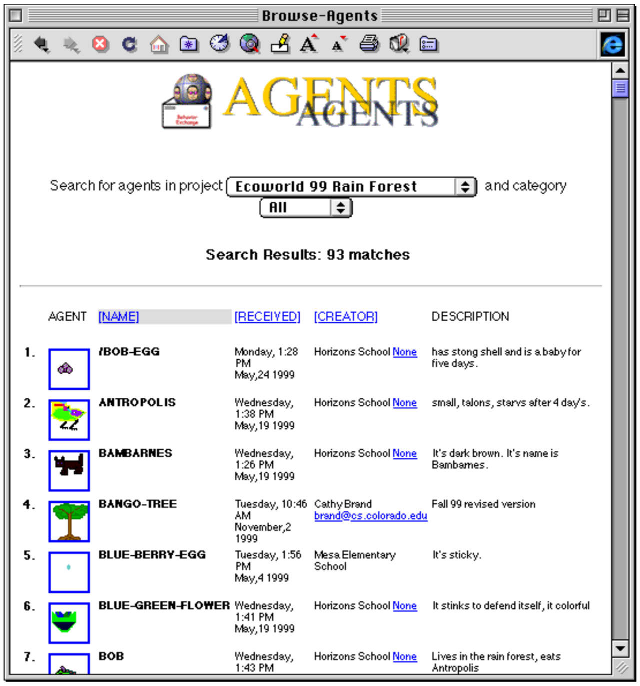

Figure 5. The Behavior Exchange is a web-based repository of agents. Users can share their agents with other users.

The process of designing animals and exchanging them to build a joint simulation is new, engaging way to learn about complex system collaboratively. The motivation of building simulations was so high that student were found to return early from their lunch breaks in order to tweak their simulations. The same students had never returned early from their lunch breaks to read books.

In this example information agents capture information processing. These agents are built and distributed as a form of collaboration between computer end-users.

High Schools: The Grape Boycott

At the high school level, simulations were used in John Zola's "Protest and Reform" history class at New Vista High School [Ioannidou, et al. 1998]. In this class, students had the opportunity to study protest movements throughout U.S. history (e.g. the Civil Rights movement and the anti-Vietnam war movement), and to learn about theories of protest and social change. Initially, simulations were used in this context to present some of the concepts of protest and reform through "Segregation" and "Protest March" simulations created by the researchers using the AgentSheets system. Students also created simulations to present their own thoughts and ideas for their final projects.

One of the groups that chose to do a final project using AgentSheets selected the topic of the California Grape Boycott in the context of the Chicano/a, Latino/a Civil Rights movement. The project, as the students defined it, consisted of building a Web page with a boycott simulation which they had created, as well as links to related Web sites. In fact, these students' Web site served as a small virtual library on the subject.

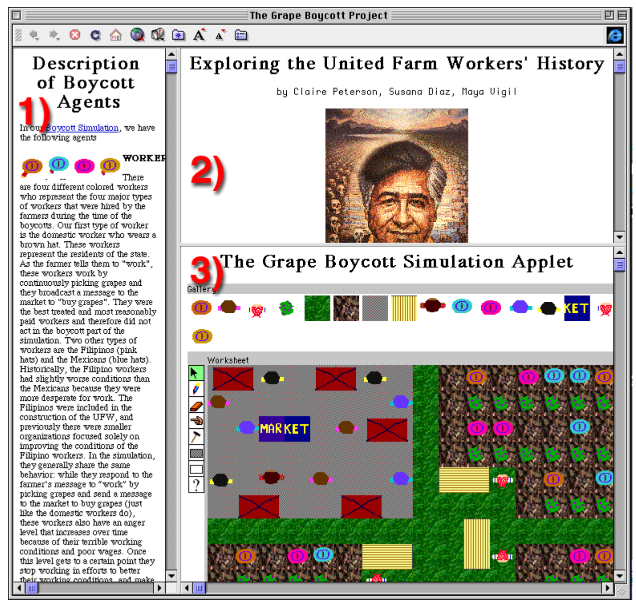

Figure 6. A student produced webpage containing a simulation of the Californian Grape Boycot

In order to build the simulation, the students realized that they needed to find out about the history of the boycott and of the United Farm Workers movement. The students did some initial research in the library and on the Web to learn the basic historical facts, and found relevant information in Web pages, which they could reference on their own Web page.

Modeling

In modeling applications simulations are used to explore complex causalities between a set of interacting variables. The reasons why people build models include issues such the price of running a physical experiment (for instance it is very expensive to explore the effects of micro gravity by putting an experiment aboard a Space Shuttle), and the danger of operating an experiment (for instance an experiment melting the core of a nuclear power plant).

Modeling is most beneficial to simulation builders. The model becomes an instrument of the explorative thinking process allowing the builder to test new hypothesis leading to new insight and understanding. An example of an interactive simulation model created by scientists at the BioServe Space Technologies center is shown below (Figure 7). The simulation models the behavior of E.Coli bacteria in micrograms and explores its implications for fermentation biotechnology [Klaus 1998].The goal of the model is to explain why E.Coli bacteria behave fundamentally different in microgravity situations such as aboard the Space Shuttle orbiting around the earth. The process of building this model has helped the BioServe scientists to better understand complex molecular interactions involving bacteria cell sedimentation cell diffusion, byproduct diffusion and nutrient uptake.

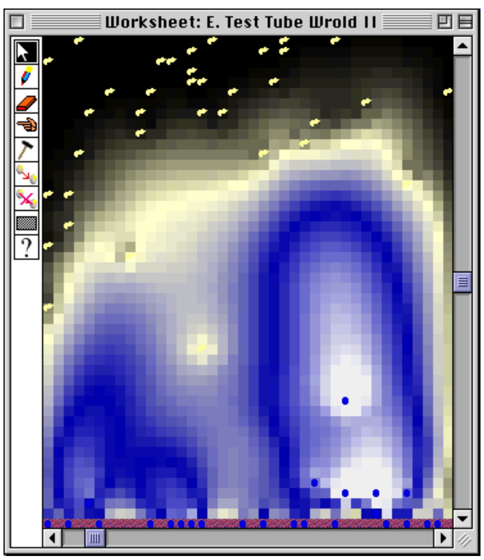

Figure 7. E.Coli bacteria are situated in a low-gravity environment and are slowly sinking toward the bottom of the cell. Glucose is absorbed and converted into waste products.

From a learning perspective modeling is useful because it helps simulation builders to explore new ground. The physical experiments that have been in the MIR space station and were part of the 5 Space Shuttle missions are costly and need extensive preparation. The simulation, in contrast, can be varied at any time and run in parameter ranges that cannot be replicated with the physical experiment.

Public Discourse

The use of simulation technology is not limited to traditional screen-with-mouse interaction approaches. New display and interaction techniques when combined with simulations result in a new kind of tangible interactive medium. Professor Ernesto Arias from the University of Colorado school of Architecture & Design is concerned with decision making as a public process. He has been using AgentSheets in many of his courses, and is now working with the Center of LifeLong Learning & Design on new interface technologies that bring the power of simulations to the public. He envisions information kiosks located in public buildings such as libraries. Using a display technology called SmartBoard, he is building simulations that combine the physical world with the virtual world. Physical objects such as LEGO blocks can be placed onto a vertical version of the SmartBoard (see Figure 8). The virtual world is an AgentSheets simulation of the Boulder bus system. Along with members of the healthy community initiative, Professor Arias is exploring issues such as public transportation and pollution. Community members experience public transportation scenarios either personally, by interacting with the physical virtual simulation, or over the web.

Figure 8. A Physical + Virtual Simulation running AgentSheets on SmartBoard (horizontal in front and vertical in back)

Connecting Simulation to other Components

Interactive simulations could be turned into a richer learning activity if they could be connected to other educational components such as plotters, databases, and spreadsheets. Addressing these kinds of issues the National

Science Foundation is supporting the Educational Software Components of Tomorrow [ESCOT] project with the goal of exploring the use of Java-based component technology in education [Roschelle, et al. 1999]. To this end ESCOT brings together researchers, practitioners, developers, curriculum designers, publishers and content experts. Along with SimCalc and Geometer's Sketchpad®, AgentSheets is one of the cornerstone ESCOT tools to generate educational components and build math activities.

In Figure 8 an AgentSheets simulation called the Virus Attack simulation is connected to the SimCalc graphing component to plot the number to infected people while the simulation is running. This allows users to track the spreading of the virus through graphical and numeric data, as well as simulated visual data.

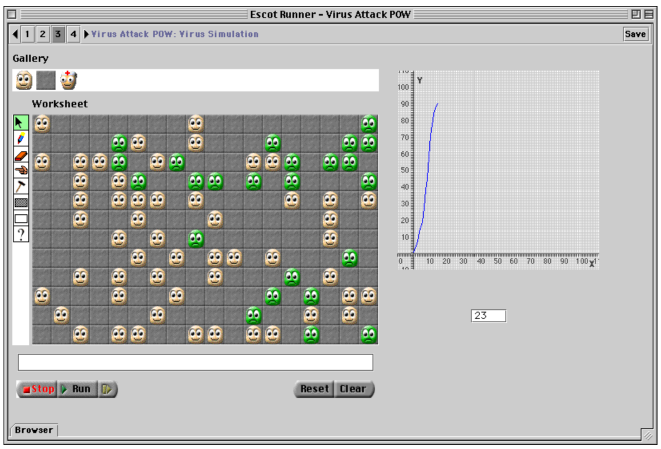

Figure 9. ESCOT Connected Math activity combining AgentSheets Virus Attack simulation component (left) with SimCalc plotting component (right).

Acknowledgements

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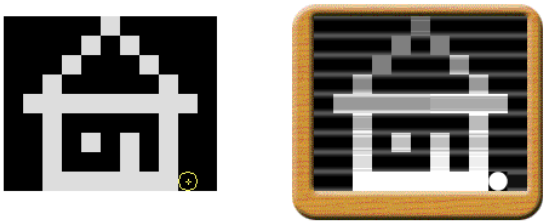
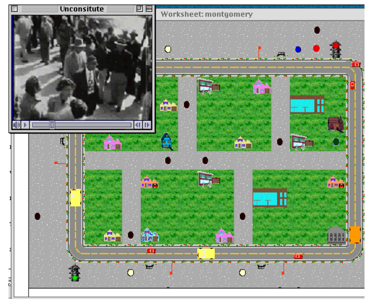
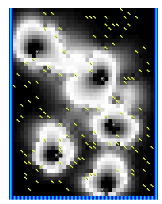
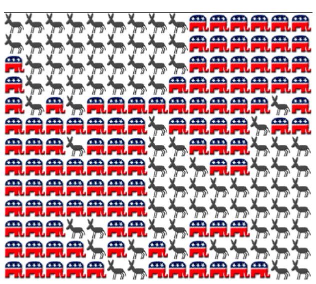
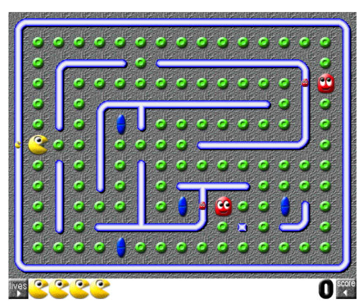
Table 1: Application Domains for Interactive Simulations

Interactive Illustrations  **How does a TV work?** This simulation illustrates how a picture is scanned in by a camera (left), transmitted to a TV set and converted back in to a picture (right). Users can paint their own pictures and play with TV signal processing parameters.	***K-12 Education: High School***  **Interactive Story Telling**: History students create interactive stories of historical events such as the Montgomery bus boycott.
Deconstruction Kits  **Learning by taking apart**: What makes a bridge stable? The goal presented to the users of this simulation is to remove as many elements of the bridge as possible without making the bridge collapse. A number of connected issues are revealed including forces, architecture, and geometric perspective. This simulation was featured on the PBS Mathline.	***Scientific Modelling***  **Learning by visualization and modeling**: The effects of microgravity onto E.coli bacteria are modelled by NASA. This is a simulation of an experiment that was aboard the Space Shuttle with John Glenn. This simulaton requires several thousand agents.
Educational Games  **Learning through simulation use**: This simple voting simulation explains concepts such as clustering, migration and stability of two party systems. Can it predict the outcome of the election in 2000?	***Non-Educational Games***  **Learning through design**: Even if the finished simulation/game is not directly related to educational goals, the process of building the simulation may be very educational. The Ultimate Pacman is a complete game based on complex Artificial Intelligence algorithms and the non-trivial math of diffusion processes.