Black hole Tell tales.

New Mexico Supercomputing challenge
Final report
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Final Report:

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Executive summary:

Our team is made up of different and opinionated people and yet when we were trying to come up with an idea of what project we wanted to study for the supercomputing challenge, everyone in the team pretty much agreed on the topic of black holes. We were curious about how scientists know where a black hole is located in space if they can't see it? We thought that it would be pretty hard to tell for sure. In Hollywood, they portray Black holes to be time traveling devices that suck up everything in sight. The true fact about Black holes is that they're holes alright; it's just that they're the end point of massive stars. People die and to some extent, stars do too but unlike people, they turn in to Black holes.

As we were reading about black holes we learned that if one was somehow able to figure out where a black hole was in space, they would have to look at evidence, or **tell tales.** The main tell tales that we could understand from reading about black holes were that:

1. When there is a black hole in vicinity of space, stars, planets, or any other celestial bodies are pulled toward an empty patch of space, which would mean that there is something heavy there. Therefore, scientists would measure the force, or how hard the stars or planets are being pulled in. The basic math that led us to understand the nature of black holes was to learn to calculate force. (Force = mass x acceleration) This was the most basic math that we could really understand as 8^{th} grade students as were learning about black holes.

2. Scientists need to figure out how heavy the object (calculate the mass of the object) that was doing the pulling. Black holes can be said to "come in all sizes", meaning that they have a wide range of masses. They know that the mass calculated for the condensed star must exceed 3 solar masses in order to be considered as a black hole; perhaps most familiar are "stellar-size black holes"; these are the black holes which form from the death of a very massive single star. They tend to have masses in the range of a few to a few tens of solar masses. Next, there are "medium-size" black holes, with masses in the range of a few hundred to a few thousand solar masses. These black holes are probably the result of the mergers and long-term evolution of stellar-mass black holes. Finally, there is what is called the "super massive black holes"; these objects have the mass of a few million to hundreds of billions of solar masses. They exist in the centers of galaxies. Black holes of lager masses have larger radius and generate more intense level of gravitational pull on nearby objects

3. Some of the **tell tales** are the gamma-ray bursts that erupt when a black hole is formed after a large star dies in a massive explosion called a supernova. What triggers this chain of events is **gravity, a force so powerful at its most extreme that it can actually warp the fabric of the cosmos**. These waves would show very precisely what space-time looks like near the place they were produced. Thus, gravitational waves give scientists a way to really see a black hole.

On Earth, if you throw a ball upwards it will come back down. Throw it faster and the ball travels further upwards. At a critical "escape" speed though (4000 mph), the ball has enough speed to completely escape Earth's gravity. But if we do the same experiment on a very massive, compact, collapsed star, we find that the escape speed is much higher. Scientists like Laplace have been asking what if there were stars so massive and compact that even moving at light speed would not allow objects to escape? A black hole is a collapsed object whose gravity is so strong that even light beams cannot escape. And therefore from Einstein's "speed limit", nothing can escape! So although you could in principle travel to a black hole, you could never report back your findings. All that your colleagues would see would be an image of you just before you disappeared into the "event horizon" which is the boundary of the back hole’s secret world within.

While it might seem hard to prove the existence of black holes, astronomers have plenty of indirect evidence that they exist, from the effects they have on their companion stars, called in falling matter, and more recently, the refracting light around them. Some of these observations have only been possible in the past 10 years. If a black hole passes through a cloud of interstellar matter, or is close to another “normal” star, it can pull matter onto itself. As the matter is pulled towards the black hole, it gains kinetic energy, heats up, and is squeezed by tidal forces. As it gets hotter, its peak radiation moves progressively through the ultraviolet, X-ray, and gamma-ray regimes. In fact, we expect X-ray emission to occur just before the matter crosses the Schwarzschild radius, (event horizon) and can use this radiation to probe the most extreme environments of gravity, density, temperature, and **velocity.** However, it is not as simple as this may sound.

Statement of the problem:

The problem that we want to investigate is to figure out the impact of mass of a black hole on neighboring celestial objects: **How the size of a black hole impacts celestial objects around it. Do all black holes have such strong tidal forces at such a large circumference from the event horizon?**

A black hole is a super massive body condensed into a relatively tiny space. Many black holes are formed when a super giant star collapses on itself and its gravity is so strong that even light, if it comes too close, cannot escape.

The detection of black holes requires more math and physics than we, who are in the 8^{th} grade, have learned. With these limitations we simplified our model to focus on one variable that can help scientists to tell where black holes are located, namely the connections between mass, volume, and density and to understand that something can collapse while maintaining the same mass.

. We used math we learned so far to calculate mass, volume, and density of different objects because, the relationship of mass, volume, and density is important as a tell tale in the location of black holes. We came up with a hypothesis that this relationship (mass,volume, density)can be used to determine how big the tear a collapsed star would make in the fabric of space and space time. With a bigger tear, it would reach further into space to suck in other planetary objects around it (and maybe objects with a greater mass).

Methodology of Problem Solution

WHAT WE LEARNED:

The most significant original achievement on the project was those of Research.

We learned a lot about black holes as you can see from the research on the above pages.

We also realized two things about this project.

1. Even this topic was fun; it was very difficult to model or to understand the math. Next time we will choose a project that we can handle.

2. IN PHYISICS/MATH

Terms to Know:
We needed to know the differences between mass and weight

Force = mass x acceleration
Weight = mass x acceleration due to gravity
Density = mass/volume)

Velocity = kilometers divided by seconds

The formula below is used to calculate the event horizon radius of a black hole for a given mass,

2Gm
R= --------
c 2

In the formula above, “R” is the radius of the event horizon in meters, “G” is the universal force of gravity ($6.67 \times 10^{-11}\ m^3\ kg^{-1}\ s^{-2}$), “m” is the mass of the star’s core in kilograms, and “c” is the speed of light (3.0×10^8 m).

From Research, we found out that (Mass of a black hole is very important)

Bigger Mass + Bigger circumference = lessen the Force of gravity

<u>Math Model:</u>

1. Mass
2. Volume
3. Density

4. **PROGRAM**

```
; ====================================
;        "Stellar Fellars"
;   The Influence of a Super Massive
;     Black Hole on its Neighbors
; ====================================
;    from original model by Uri Wilensky
;   (see below for full copyright info)
;        adapted by Lisa Goldman
;    with Greg Malone and Pat Higgins
;   Santa Fe Institute Summer Workshop
;             June 2003
```

adapted again by team 26

Supercomputing Challenge 2007

<u>Observer Procedures</u>

```
;  ====================================
;   The Influence of a Super Massive
;     Black Hole on its Neighbors
;  ====================================
;   from original model by Uri Wilensky
;  (see below for full copyright info)
;       adapted by Lisa Goldman
;   with Greg Malone and Pat Higgins
;  Santa Fe Institute Summer Workshop
;             June 2003



to setup                        ; tied to setup button on interface
  ca
  crt 30
  setg 0.5
  setstate 1
  create-and-do number
```

```
 [
   setc white
   setxcor (random (screen-width - 5))
   setycor (random (screen-width - 5))
   if who = 0 [setc red setxcor 0 setycor 0 seth random 360]
   set vx 0
   set vy 0
   set xc xcor
   set yc ycor
 ]
end
```

Turtle Procedures

```
;  DECLARE VARIABLES


turtles-own
[ fx     ;; x-component of force vector
  fy     ;; y-component of force vector
  vx     ;; x-component of velocity vector
  vy     ;; y-component of velocity vector
  xc     ;; real x-coordinate (in case particle leaves screen)
  yc     ;; real y-coordinate (in case particle leaves screen)
  r-sqrd ;; square of the distance to the mouse
  wander
```

```
  heading
]

globals
[ m-xc  ;; x-coordinate of acting mass
  m-yc  ;; y-coordinate of acting mass
  g     ;; Gravitational Constant to slow the acceleration
  state
  move
  track
]
; MAIN LOOP
to eventhorizon        ; outline of the event horizon to make it visible
fd 10
rt 50
end
to gravitate                          ; tied to button on interface

    set m-xc xcor-of 0                ; object 0 is our black hole attractor
    set m-yc ycor-of 0                ; initialize coords of "acting mass"

    update-force                      ; STEP ONE
    update-velocity                   ; STEP TWO
```

```
    ifelse who = 0
    [update0]                        ; update object 0, our massive attractor
    [update-position]                ; and update all other objects too

end
;

; NOW, THE SUBROUTINES
to update-force                      ; update the force for all objects

        ;; Similar to 'distancexy-nowrap', except using an unbounded plane.
        set r-sqrd (((xc - m-xc) * (xc - m-xc)) + ((yc - m-yc) * (yc - m-yc)))

        ;; prevents divide by zero
        ifelse (r-sqrd != 0)
        [
        ;; Calculate component forces using inverse square law
        set fx ((cos (atan (m-yc - yc) (m-xc - xc))) * (mass / r-sqrd))
        set fy ((sin (atan (m-yc - yc) (m-xc - xc))) * (mass / r-sqrd))
        ]
        [
        ;; if r-sqrd = 0, then it's at the mass, thus there's no force.
```

```
        set fx 0
        set fy 0
        ]
end

to update-velocity                     ; update the velocity component

        ; Now we update each particle's velocity, by taking the old velocity and
        ; adding the force to it.
        set vx (vx + (fx * g))         ; note the gravitational variable being applied
        set vy (vy + (fy * g))
end
to update-position                     ; update xy coordinates of objects
        set xc (xc + vx)
        set yc (yc + vy)
        ;; If we're in the visible graphics screen, update our x and y coordinates.
        ifelse ((xc >= (0 - (screen-width / 2))) and (xc <= (screen-width / 2))
        and (yc >= (0 - (screen-width / 2))) and (yc <= (screen-width / 2)))
        [
        setxy xc yc
        if track = 1 [stamp 47]        ; track with yellow
```

```
 ]

        ;; If we've moved off of the screen, kill the object

        [ die ]


end to up date0

if move = 1 [

setheading heading + wanderangle

seth heading

repeat 5 + random 5  [fd 5 wait .01]

]


end
```

; This model was converted to NetLogo (and was changed in the process to

; be an alternate version of the model) as part of the project:

; PARTICIPATORY SIMULATIONS: NETWORK-BASED DESIGN FOR SYSTEMS LEARNING IN

; CLASSROOMS. The project gratefully acknowledges the support of the

; National Science Foundation (REPP program) -- grant number REC #9814682.

; Converted from StarLogoT to NetLogo, 2002. Updated 2002.

;

; To refer to this model in academic publications, please use:

; Wilensky, U. (1998). NetLogo Gravitation model.

; http://ccl.northwestern.edu/netlogo/models/Gravitation.

; Center for Connected Learning and Computer-Based Modeling,

; Northwestern University, Evanston, IL.

;

<u>RESULTS</u>

Scientists are now beginning to find ways observational evidence for the existence of both stellar-mass and supermassive black holes. How has this happened? If a black hole passes through a cloud of interstellar matter, or is close to another “normal” star, the black hole can pull matter onto itself. As the matter is pulled towards the black hole, it moves faster, heats up, and is squeezed by tidal forces. As it gets hotter, its peak radiation moves progressively through the ultraviolet, X-ray, and gamma-ray regimes. In fact, X-ray emission occur just before the matter crosses the event horizon. Now scientists know that in order to find a blackhole, the **tell tales** are that; the mass calculated for the condensed star must exceed 3 solar masses in order to be considered as a black hole; know that a characteristic “double-horn” shape will be introduced into the spectrum of a black hole due to a gravitational red shift; know that the X-ray emission from a black hole should be highly variable in time. But are any of these methods a fool proof way of identifying black holes to the exclusion of any other type of celestial object? The answer is not yet clear. In our StarLogo model, we simulated the mass falling into a black hole and varied the mass of the black hole.

Conclusions:

We wanted to find out how the size of a black hole impacts celestial objects around it. Do all black holes have such strong tidal forces at such a large circumference from the event horizon? Based on our research, we found out that, yes, the size of a black hole impacts celestial objects around it. One of the ways that the mass impacts celestial bodies around it is from the aggregation of matter around it**; the larger the mass of the black hole, the weaker the tidal forces will be!** This seemingly paradoxical situation has a simple origin: the tidal force is proportional to the hole's mass divided by the cube of its circumference. So, as the mass grows and the horizon circumference grows proportionally, the near-horizon tidal force actually decreases. For a black hole weighing a million solar masses, the tidal force is 10 billion times weaker than it is for a 10 solar mass black hole.

DISCUSSION

We began this project with incredible excitement. We were curious about black holes. We learned the most by doing research and reading about black holes. We also visited the Natural History museum in Albuquerque where Thuso, our mentor, works. He invited us to see the show they had at the museum about black holes and explain the phenomena of black holes to us.

We learned a lot of math by calculating mass, density, circumference, radii of different objects to try to make a connection between mass, circumference, and fall of different objects.

We research starlogo models and were unsuccessful to find a model that we could follow. We finally found the above model and used it to change mass/circumference/gravity relationships.

Without understanding higher math, we now realize that our project was too advanced. We will continue working at it as our math skills improve.

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Wilensky, U. (1998). NetLogo Gravitation model.

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