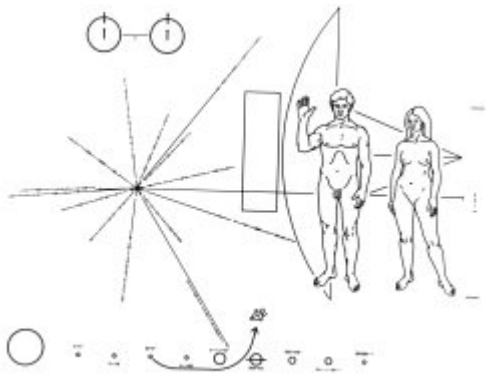
Exploring Binary

Binary Code on the Pioneer 10 Spacecraft

By Rick Regan March 6th, 2009

The Pioneer 10 (also known as Pioneer F) spacecraft, launched in 1972 and now on a *very* long journey towards Taurus, has a plaque mounted on it which is designed to inform alien civilizations about the spacecraft's origin. The plaque contains a diagram of our solar system, the trajectory of the spacecraft, a drawing of a man and woman, and groups of vertical and horizontal strokes — you guessed it, binary code — that gives information about how to find us:

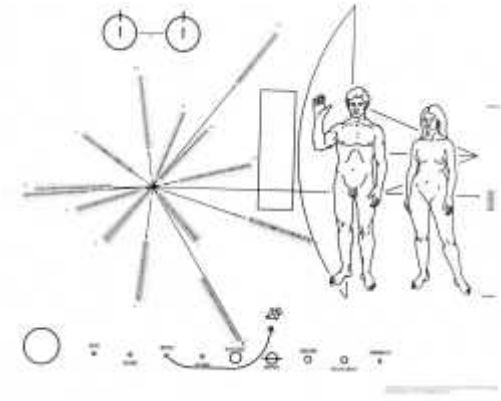


Pioneer 10 Plaque (click image for higher resolution).

Disclaimer: I'm a computer scientist, not a physicist or astronomer.

Binary Encoding

The binary information in the diagram is encoded as groups of vertical strokes (|) and horizontal strokes (—). | means 1, and — means 0. For example, |—|— is 1010. Each group of strokes represents a binary integer, and there are binary integers associated with three entities: pulsars, planets, and people. I've annotated the original diagram and highlighted their encodings in gray:



Annotated Pioneer 10 Plaque (click image for higher resolution).

Hydrogen As a Yardstick

The hydrogen atom, indicated by the two circles at the top left of the diagram, serves as a universal reference for time and distance. Specifically, the atom's hyperfine transition, which is about 1420 MHz, is the base of measure. A frequency of 1420 MHz gives a period of about $7.04 * 10^{-10}$ seconds, and a wavelength of about 8.3 inches. These numbers are implied as units in other parts of the diagram.

Pulsars

There are 14 radial lines in the diagram, representing the positions of 14 pulsars relative to the sun. Pulsars emit radio waves at a different frequencies, which helps identify them. The waves emanate across much of the galaxy, so presumably an alien culture could detect them and locate our solar system. Also, since a pulsar's frequency decreases with time, aliens could use that to determine when the spacecraft was launched.

Each pulsar line is labeled with an encoded binary integer, which is read in the direction of the gray arrows I've drawn. Starting at the unlabeled line (appearing at 3:00 in the diagram) and heading clockwise, those numbers and their decimal equivalents are:

Binary Encoding of Pulsar Periods

Pulsar Number	In Binary	In Decimal
1	1000110001111100100011011101010	1,178,486,506
2	1011001001100010101110110111	374,101,871

3	10000011011001011000100111000	551,117,432
4	11110001101101100101010011	126,726,823
5	10101011011001101100101000011	359,455,043
6	10110011101101010101111000101	753,751,947
7	1011001110000010101000010	47,057,538
8	10011110100011010100010011100	5,320,116,676
9	11110001111110001111100001011	1,014,906,390
10	10110110010110100100001011000	764,842,161
11	10111100111100111001100000	792,520,205
12	11110010111110001110100011110	509,549,854
13	10011001011010111010010111000	321,746,104
14	10000011010010101000111010	550,675,372

These numbers represent the period of the pulsar's radiation, counted in units of $7.04 * 10^{-10}$ seconds. Multiply each integer by $7.04 * 10^{-10}$ to get the period.

Planets

The binary code for each planet indicates its average distance from the sun. (Pluto is included because it was still considered a planet in 1972.) The distances are relative to Mercury's distance from the sun, which is given as 10 units. For example, Saturn is 24.7 times farther from the sun than Mercury. Confusingly, the wavelength derived from the hydrogen atom plays no role in these values.

Binary Encoding of Distance from Sun

Planet	In Binary	In Decimal
Mercury	1010	10
Venus	10011	19
Earth	11010	26
Mars	100111	39
Jupiter	10000110	134
Saturn	11110111	247

Uranus	111101111	495
Neptune	1100001100	780
Pluto	1111111100	1,020

People

The height of the woman in the diagram is encoded by the |— — —, which is 1000, or 8 in decimal (nevermind that it's written from the bottom up and one of the horizontal strokes has a defect in it). If you multiply this by the reference unit of length, 8.3 inches, you get the height of the woman — about 5 feet, 6 inches.

Commentary

Will aliens know how to read binary code? Will they know that the binary code represents binary integers? Will they understand that the units of distance and time associated with those integers, in most cases, are derived from properties of the hydrogen atom? Will they make numerous other assumptions required to understand that plaque? Not likely. But the scientists wanted to make an attempt at communication, and having chosen binary is a testament to its simplicity and universality.

Other References

1. A funny, yet informative, article about the plaque.
2. Details on the science of pulsars.
3. The Pioneer 11, also known as Pioneer G, was launched in 1973, with the same plaque.

(Images courtesy of NASA).

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7 comments

1. **Bruce Steo**

   December 15, 2009 at 11:08 pm

   Thank you. This is a great article. I really appreciate you writing it.

2. **Bruce Steo**

   December 15, 2009 at 11:13 pm

By the way, the distances at the bottom of the plaque use a different font for the "1" digits. It uses something like a Roman Numeral "I" ("seriff" with "feet" as opposed to "sans seriff") this is so that the space aliens would just know that this font change signals the change to calculations unrelated to hydrogen. Seriously, that's what a 1973 article about the plaque says.

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3. **Rick Regan**

December 16, 2009 at 9:34 am

Bruce,

Interesting, thanks. Any chance that 1973 article is online somewhere?

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4. **Bruce Steo**

December 20, 2009 at 7:22 pm

Dear Rick:

Yes, it was scanned many years ago, but it appears whoever did the scanning did not understand what to do. Instead of saving it as a text file, the article is saved as artwork, as a jpg file. You will have to save the web pages that it is on, and then use adobe photoshop or microsoft paint to open it and zoom it and read the very grainy text.

Each piece of the article is located here:

http://www.enterprisemission.com/images/plaque-1.jpg
http://www.enterprisemission.com/images/plaque-2.jpg
http://www.enterprisemission.com/images/plaque-3.jpg
http://www.enterprisemission.com/images/plaque-4.jpg

Have a good day,

Bruce Steo

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5. **Rick Regan**

December 20, 2009 at 10:29 pm

Bruce,

Wow — great stuff. Thanks! My eyes hurt from reading it, but it was worth it. (Oddly, under Firefox, I get "403 Permission Denied"; but the images load under IE.)

I like the detailed rationale they give as to why they think it will be interpreted correctly; it still may be a stretch, but they make good arguments.

Here are some quotes I liked:

"The serifs on the binary "ones" are presented to stress that the units are different from those of pulsar length and period." (RR: Bruce, this is the one you pointed out.)

"The large number of digits is the key that these numbers indicate time intervals, not distances or some other quantity. ... There are no other
conceivable quantities that we might know to ten significant figures..."

"The problem of which end of a number is the most significant digit is expressed automatically in this formulation, since all binary numbers start with a 1 but end in a 1 or a 0." (RR: this is how you know to read the binary numbers correctly, which is in the direction I've drawn the arrows).

"The binary notation, in addition to being the simplest, is selected in order to produce a message that can suffer considerable erosion and still be readable. In principle, the reader only need to determine that there were two varieties of symbols present, and the spacings alone will lead to a correct reconstruction of the number."

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6. **Bruce Steo**

May 13, 2010 at 10:20 am

Dear Rick:

Here is a handy chart that students might like to use:

100 centimeters = 1 meter
convert meters to centimeters by multiplying by 100
299792458 meters per second = C (speed of light)

29979245800 centimeters per second = C (speed of light)
1427583133 hertz = f (Frequency for Hydrogen)
21 centimeters = lambda (wavelength for Hydrogen)
7.004845999 X 10 -10 (period for Hydrogen) = T
0.0000000007004845999 seconds = T = period for Hydrogen

lambda is a letter of the greek alphabet used for wavelength

T is the letter used in physics to represent period
T= the time needed for just one wave (the period)

C is the letter used in physics to represent speed of light
hertz means "waves per second," or frequency

velocity (speed of light) = frequency (hertz) X wavelength (lambda)
velocity = frequency X wavelength

T= period = 1/frequency (hertz)

wavelength (lambda) = velocity (speed of light) / frequency (hertz)

one second
1427583133
10101010001011100110000100111101
| – | – | – | – – – | – ||| – – || – – – – | – – ||| – |

one minute
85654987980
1001111110001011011111011001001100 1100
| – – |||||| – – – | – || – |||| – || – – | – – || – – || – –

one hour
5139299278800
1001010110010010110000110111001111111010000
| – – | – | – || – – | – – | – || – – – – || – ||| – – ||||||| – | – – – –

one day (24 hours)
123343182691200

11100000010111000010010100101101111101110000000
||| – – – – – – | – ||| – – – – | – – | – | – – | – || – ||||| – ||| – – – – – – –

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7. **tom**

June 9, 2012 at 10:09 am

The map of the Solar System doesn't show any of the satellites in orbit around any of the other worlds that are pictured. Saturn is shown with a line through it? And you had Pluto, but not Ceres or Sedna or Quaror? This is pretty much nit picking, but would the 'aliens' assume we thoroughly mapped our own star system before we launched an 'Interstellar probe'? With the primitive nature of the technology designed in the craft... could it be concluded that the probe was used only as a 'flyby' and had no propulsive or extreme long life power to do an interstellar mission? Could the decayed RTGs be used as a way to date the 'age' of the probe? Since the pioneer was shown twice in the plaque, will they use its 'scale' to measure the 'humans'? The male has 5 fingers spread with one hand;and the probe is shown flying inclined around the 5th planet? When the pioneer has been sitting in an alien museum for 10 million years, will the message be understood?

Comments are closed.