# Mandelbrot Sets

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# How to use Sage

- Go to: www.sabenb.org in order to access the notebook
- Go to: http://sagemath.org in order to download SAGE.
- (Note: You don’t need to download SAGE to use it! You can just access the notebook online to use it!)

# SAGE API

- http://www.sagemath.org/doc/reference/

# Definition

- All the complex numbers such that:
  - $$Z_{n+1} = Z_n{}^2 + c$$
  - Is bounded.
    - i.e. If $Z_{20} < 2.0$ then we will assume it is bounded!
  - By definition $Z_0 = 0$
    - More information on http://en.wikipedia.org/wiki/Mandelbrot_set

# Example

- Complex number c = 2 + 2i

$Z_0 = 0$ $\quad Z_1 = Z_0{}^2 + (2+2i)$ $\quad Z_2 = Z_1{}^2 + (2+2i) = (2+2i)^2 + (2+2i) = (2+10i)$

$Z_3 = (2+10i)^2 + (2+2i) = (-94+42i)$

$$Z_{20} = (5.8x10^{263801} + 8.9x10^{263801} i)$$

$$For\ sake\ of\ simplicity, assume\ Z_{20} = (40+40i)$$

$$abs(Z_{20}) = \sqrt{40^2 + 40^2} = \sqrt{1600+1600} = \sqrt{3200} = 56.56$$

$$For\ sake\ of\ simplicity, assume\ Z_{20} = (40+40i)$$

$$56.56 > 2.0$$

So it is not bounded.

# Example 2

$$C = 0 + 0i$$

$$Z_0 = 0$$

$$Z_{20} = 0^2 + 0i$$

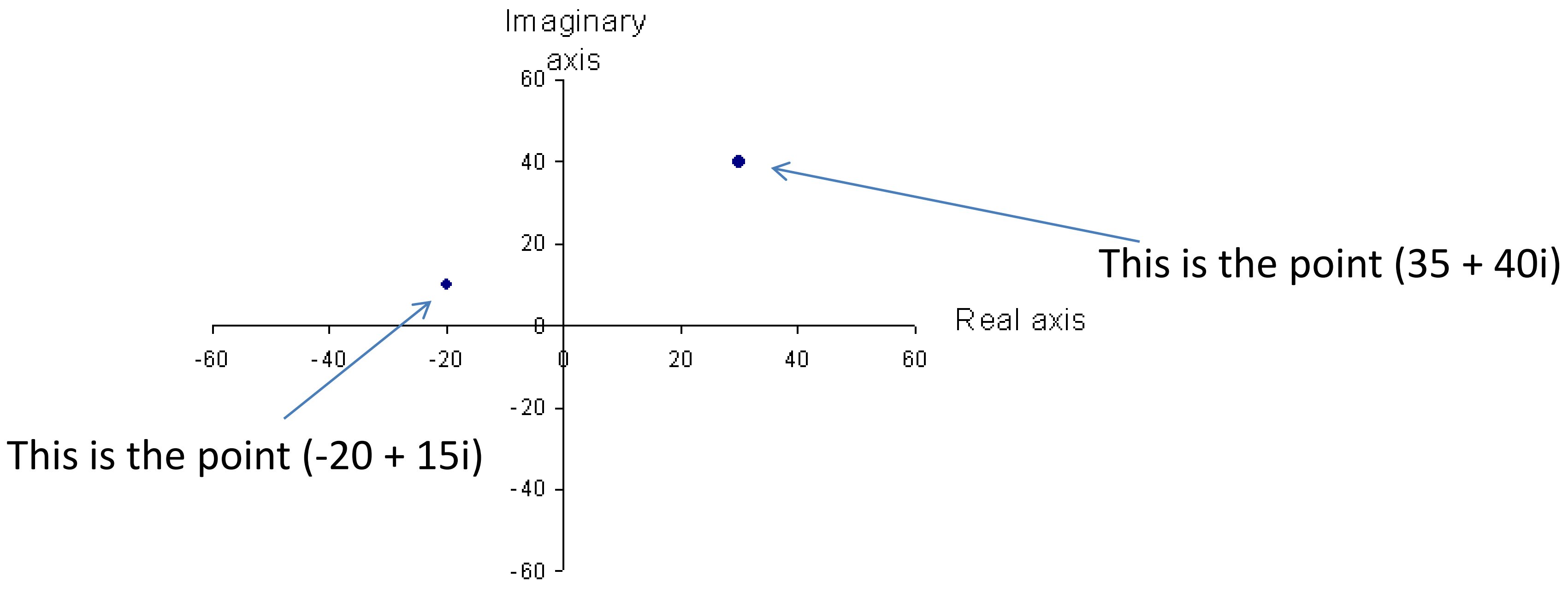
$$abs(Z_{20}) = \sqrt{0^2 + 0^2} = 0$$

$$0 < 2$$

So it is bounded. Therefore, the point (0 + 0i) is in the Mandelbrot Set.

# Complex Plane

- It looks just like the Cartesian coordinate plane, except the "x-axis" is the real numbers and the "y-axis" is the imaginary parts.
- Real numbers are complex numbers without the "imaginary" part.
- Complex number = 2 + 3i
- real imaginary


Imaginary axis
60
40
20
0
-20
-40
-60
Real axis
-60
-40
-20
0
20
40
60
This is the point (35 + 40i)
This is the point (-20 + 15i)