Quantifying Coral Morphology through Fractal Dimension

Cathy Chang

Advisor: Prof. Vianney Denis

Outline

1. Introduction & Background
    a. Current methods in quantifying coral morphology
    b. Fractal Dimension
2. Materials and Methods
3. Discussion
4. Next Steps

Current Methods in Coral Categorization

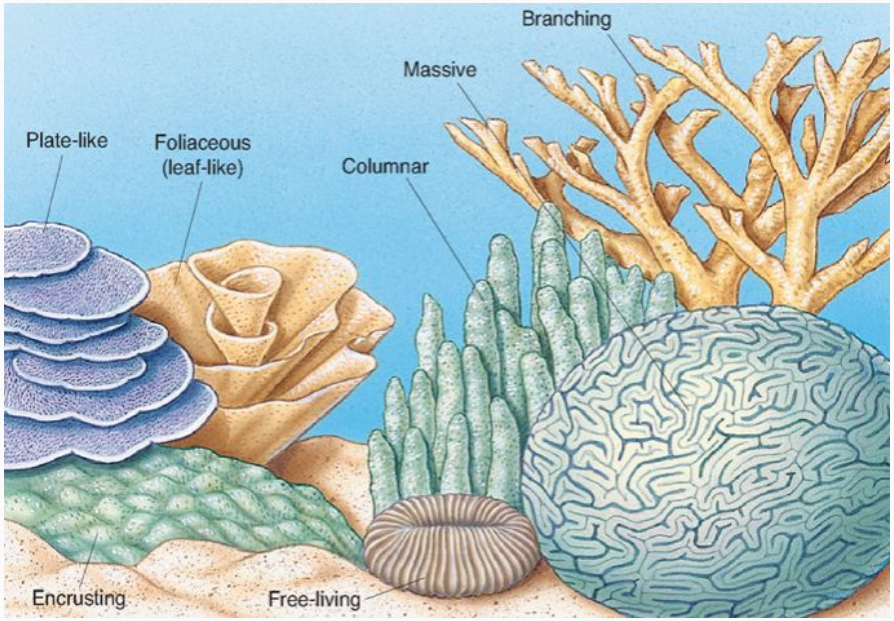
Trait-based Categorization

Submassive corals: massive and branching

Columnar: it's submassive or branching

Encrusting: many corals start off as encrusting then grow into other forms

Branching: both aborescent and bushy



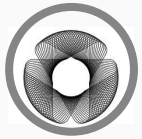
Interpretations are Subjective!

Current trait-based coral growth categorization is **loose in definition.**

Alternative method: DNA Identification

- DNA **fragmentation/ degradation**
- Break off corals

Species identification is often through naked eye; **prone to subjectivity**.



Corals are **irregularly shaped organisms**, similar to many organisms found in nature.

Desire: shift from **qualitative** to **quantitative** statistical approaches to **safely** & **efficiently** identify **irregularly shaped** corals.

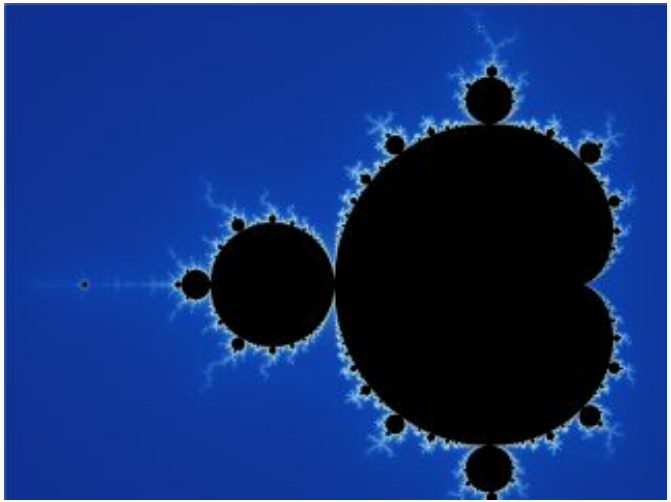
Introducing: Fractal Dimension

What is a Fractal?

“Rough or fragmented geometric shape that can be split into parts each of which is (at least approximately) a reduced-size copy of the whole"

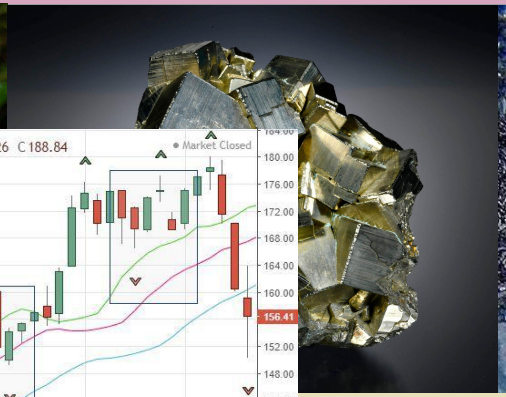
Benoit Mandelbrot, 1983

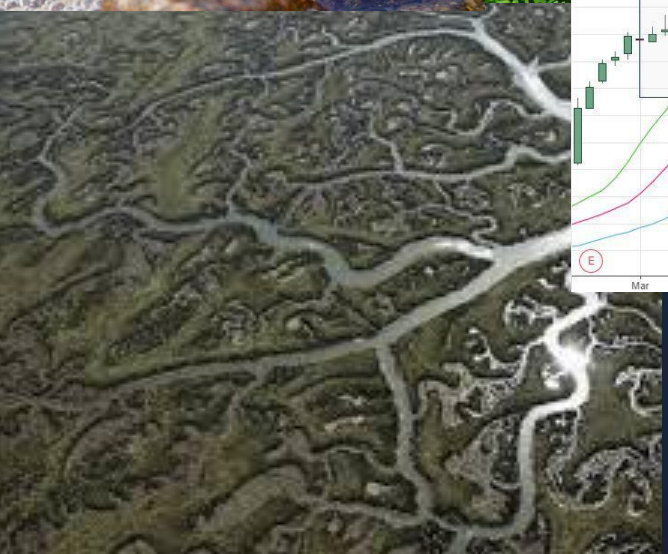
- Statistically self-similar
- Has non-integer **fractal dimension**
- Studied by the field of Fractal Geometry

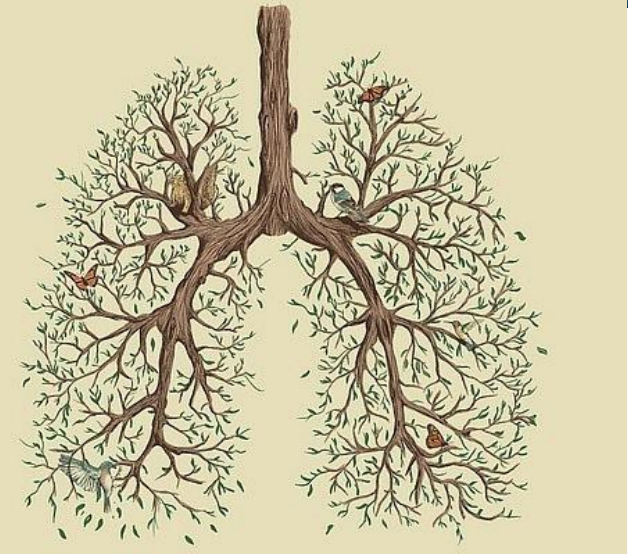


fractal	Euclidean
modern invention	traditional
no specific size or scale	based on a characteristic size or scale
appropriate for geometry in nature	suits description of man made objects
described by an algorithm	described by a usually simple formula

Nature Conforms to Fractal Geometry!







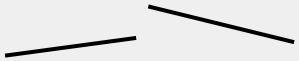

© Peter Kragh
0180

Fractal Dimension

$$N = s^{-D}$$

Dimension = 1

Lines



$N = \frac{1}{s}$

s	N	illustration
1	1	
1/2	2	
1/3	3	

1 < D < 2

Jagged lines

Dimension = 2

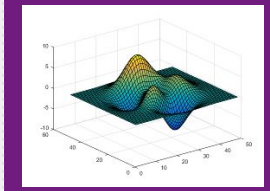
Squares, Circles, etc.

$N = \frac{1}{s}^2$

s	N	illustration
1	1	
1/2	4	
1/3	9	

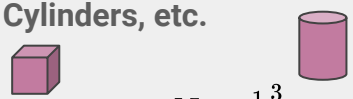
2 < D < 3

Convoluted surfaces



Dimension = 3

Boxes, Spheres, Cylinders, etc.



$N = \frac{1}{s}^3$

s	N	illustration
1	1	
1/2	8	
1/3	27	

Fractal Dimension

Parameter in characterizing roughness of an object and performing complexity analysis

- **Advantages:**
  - Sensitive to structural changes in the object
  - Orientation & scale invariant
- **Various methods:**
  - Cube Counting method
  - Bouligand-Minkowski method
- **Uses:**
  - Describing ecological systems (population, community, landscape)
  - Insect movements
  - Image process/analysis
  - Chaotic trajectories
  - Arteries (blood movement path)

General formula:

$$D = lim_{s \to 0} \frac{\log n}{\log 1/s}$$

Box/Cube Counting Method

Step 1

measure how many boxes (N) of specified length (s) are required to cover the perimeter

Step 2

Scale down and measure again.

Step 3

Repeat steps 1-2 multiple times

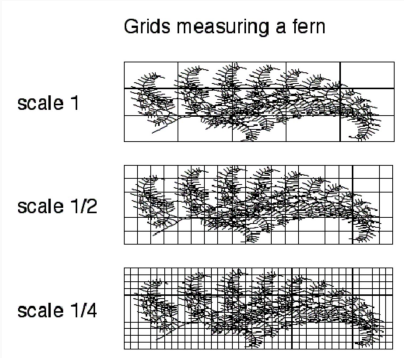
Step 4

Create log-log plot of number of boxes (N) vs scale (s)

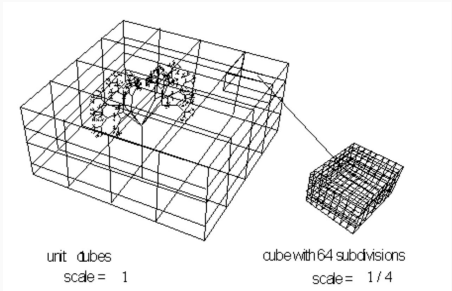
Step 5

Find the slope of the plot

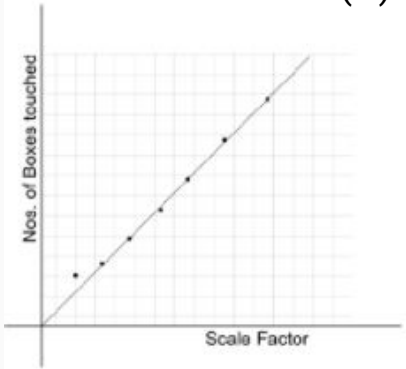
2D



3D



Graph of scale (s) vs number of boxes (N)



Aim

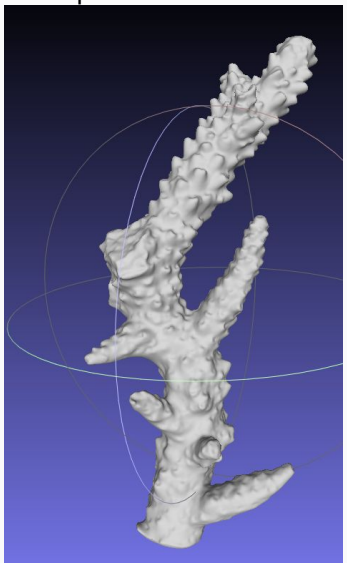
Evaluate **fractal dimension** with **cube counting method** as a variable in quantifying coral morphology

Materials & Methods

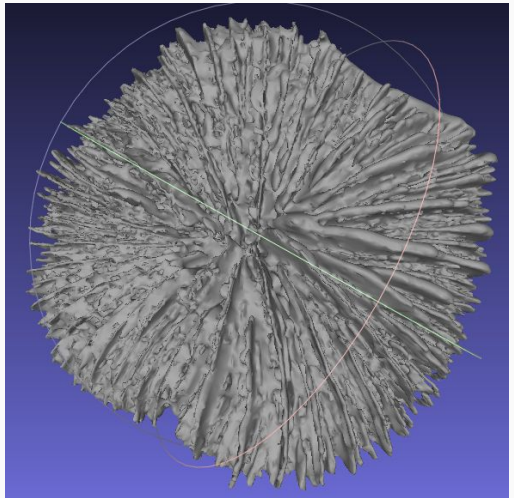
Research Methodology: Materials

3D scan 46 corals from the NTU Coral Museum & obtain .obj files

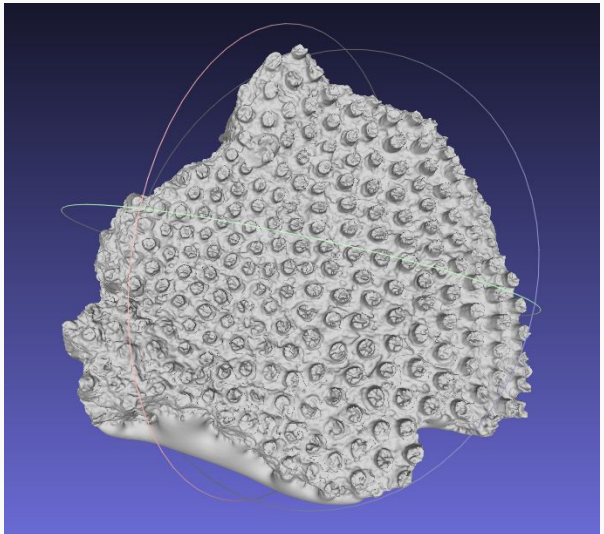
Acropora secale - 1600



Heliofungia actiniformis - 2490



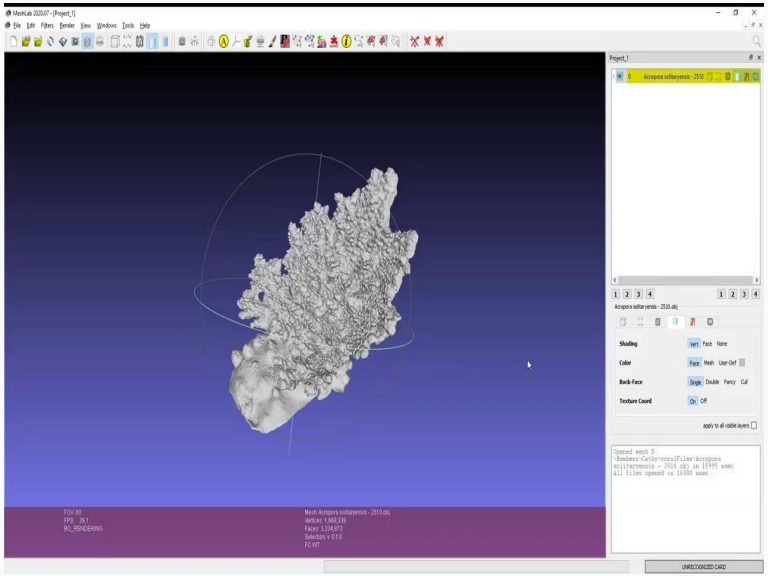
Galaxea Astreata - 1493



Research Methodology: File Modification

Modify the files (if necessary) to omit non environment-facing portions

- Not characteristic of the corals

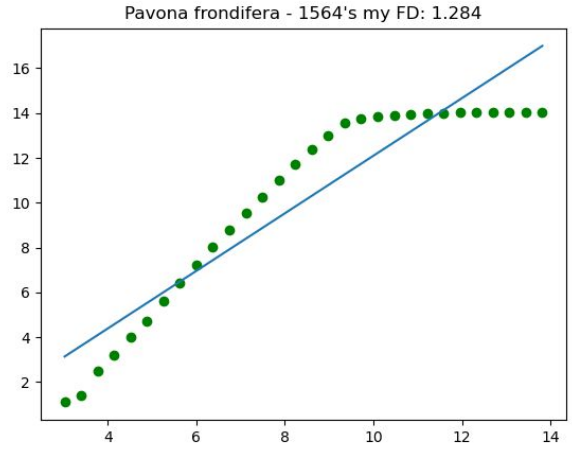


Research Methodology: Cube Counting

1. Determine the sizes of the boxes used in the box counting method
   a. Spread evenly over a log2 scale to obtain a smooth log-log plot
2. Find the number of cubes required to cover all vertices at each box size
3. Create the log-log plot
4. Revise the log-log plot with starting & ending point

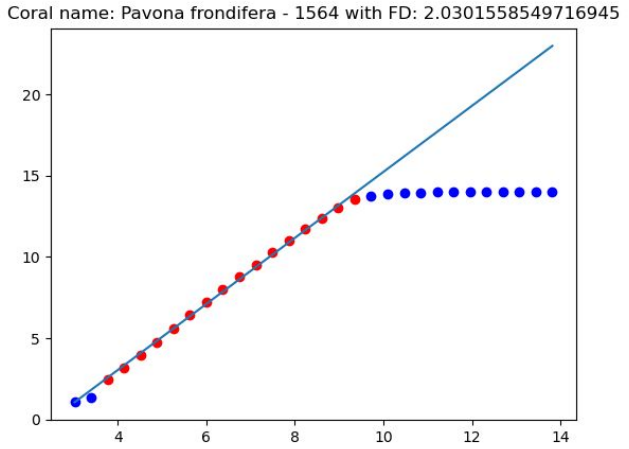
```
def bucket_fractal_dimension(array, boxDimensions, n_samples = 30, max_box_size = None, min_box_size = 0.001):
    print("Doing bucket fractal dimension analysis")
    #determine the scales to measure on
    if max_box_size == None:
        #default max size is the largest power of 2 that fits in the smallest dimension of the array:
        max_box_size = (np.min(boxDimensions))
        print("Max box size: {} Min box size: {}".format(max_box_size, min_box_size))
```

```
File Name: | Surface Area (mm^2) | Volume (mm^3) | myFD | OnlineFD | FileFD | numVertices | boundLength | boundWidth | boundHeight |
myX | myY
```




```
 2.2092822251492685 | 0 | 2.151719560050161 | 26
70546, 2.4340861282096 8, 2.8556203663486697, 3.
557043979, 5.3848257951830405, 5.806360033322101
36652851 8, 10.864770890990842, 11.2863051291299
3826689592, 5.351858133476067, 6.373319789577012
90873721087, 14.564303837616346, 14.653050680379
711555976089, 14.725790108035265, 14.79180341205
 61957.25099385123 | 2.069766011072675 | 0 | 2.0
2357954291848 2398069815, 3.9914893669
2424984715, 5.880724211379695, 6.2585711802646 5,
7348063844 4, 10.770881675769415, 11.548428744 5
3166201943 9, 13.437666989079234, 13.81591955796
901544526, 9.347926034928745, 10.09948788525 083
4973374649, 13.132767070819693, 13.1408808655373
7373046135, 13.155916134925068, 13.1566797763523
```

1. Find average slope in the range of points
   a. Starting at point where slope>0.5
   b. Ending at point where slope<0.5
2. Find start point where the slope is within 25% of the average slope
3. Find end point where slope is <60% of the average slope



Advantages & Disadvantages

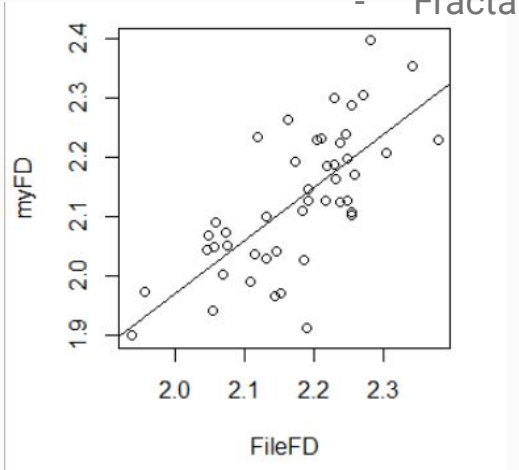
Advantage

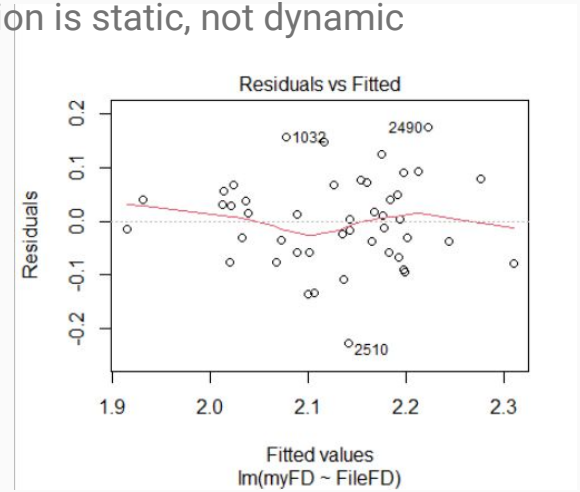
- Orientation invariant
- Deterministic way to evaluate starting & ending scales
- File modification to reduce data that may contribute noise

Disadvantage

- Not looking at interior space; only looking at shell
  - Density
- Incomplete coral models
- Fractal dimension is static, not dynamic

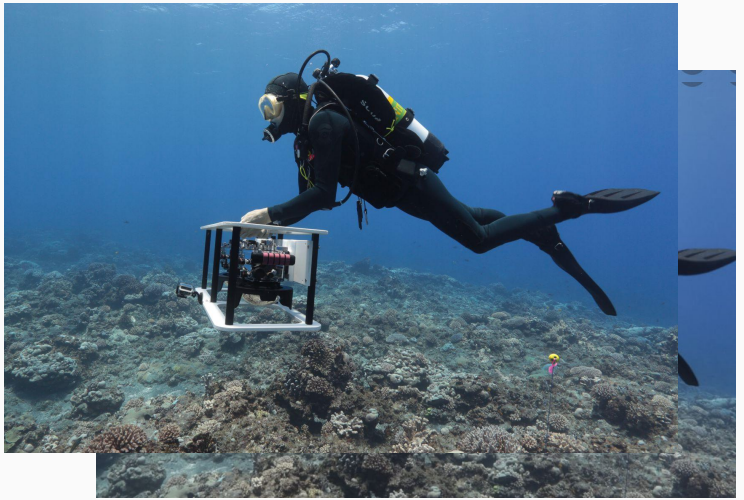
```
Call:
lm(formula = myFD ~ FileFD, data = coral_data.useful)

Residuals:
      Min        1Q    Median        3Q       Max
-0.228110 -0.058253  0.004374  0.054694  0.174214

Coefficients:
            Estimate Std. Error t value Pr(>|t|)
(Intercept)   0.1933     0.2852   0.678    0.501
FileFD        0.8891     0.1310   6.787 2.35e-08 ***
---
Signif. codes:  0 ‘***’ 0.001 ‘**’ 0.01 ‘*’ 0.05 ‘.’ 0.1 ‘ ’ 1

Residual standard error: 0.08326 on 44 degrees of freedom
Multiple R-squared:  0.5115,    Adjusted R-squared:  0.5004
F-statistic: 46.06 on 1 and 44 DF,  p-value: 2.347e-08
```





Next Steps

- Photogrammetry
- Automatic species identification
- Colony scale
- Characterize individual corals' theoretical fractal dimension
  - Stochastic processes
  - ODE
- Multi-Scale fractal dimension




Thank You!