- Previous Lecture:
  - Nested loops
  - Developing algorithms and code
- Today, Lecture 8:
  - Review nested loops
  - User-defined functions, part 1
- Announcement:
  - Project 2 due Monday 2/17 at 11pm
  - Watch MatTV episode “Executing a Function”
  - Lunch with instructors! RSVP via website survey. Friday, Feb 14, Risley Hall, 11:50

Rational approximation of π

- π = 3.141592653589793…
- Can be closely approximated by fractions,
  e.g., $\pi \approx 22/7$
- Rational number: a quotient of two integers
- Approximate π as p/q where p and q are positive integers $\leq$M
- Start with a straight forward solution:
  - Get M from user
  - Calculate quotient p/q for all combinations of p and q
  - Pick best quotient → smallest error

```
% Rational approximation of pi

M = input('Enter M: ');




% Check all possible denominators
```

```
% Rational approximation of pi

M = input('Enter M: ');




% Check all possible denominators
for q = 1:M








end
```

```
% Rational approximation of pi

M = input('Enter M: ');




% Check all possible denominators
for q = 1:M
```

For current q find best numerator p…
Check all possible numerators

```
end
```

```
% Rational approximation of pi

M = input('Enter M: ');




% Check all possible denominators
for q = 1:M
   % At this q, check all possible numerators
   for p = 1:M






   end
end
```

Pattern: Best in set

Algorithm: Finding the best in a set

```
Init bestSoFar (value & quality)
Loop over set
    if current is better than bestSoFar
        bestSoFar ← current
    end
end
bestSoFar is best overall
```

```
% Rational approximation of pi

M = input('Enter M: ');
% Best q, p, and error so far
qBest=1;  pBest=1;
err_pq = abs(pBest/qBest - pi);

% Check all possible denominators
for q = 1:M
    % At this q, check all possible numerators
    for p = 1:M





    end
end

myPi = pBest/qBest;
```

```matlab
% Rational approximation of pi

M = input('Enter M: ');
% Best q, p, and error so far
qBest=1;  pBest=1;
err_pq = abs(pBest/qBest - pi);

% Check all possible denominators
for q = 1:M
    % At this q, check all possible numerators
    for p = 1:M
        if abs(p/q - pi) < err_pq  % best p/q found
            err_pq = abs(p/q - pi);
            pBest= p;
            qBest= q;
        end
    end
end

myPi = pBest/qBest;
```

piFrac.m

```
% Complicated version in the book

M = input('Enter M: ');
% Best q, p, and error so far
qBest=1;  pBest=1;
err_pq = abs(pBest/qBest - pi);
% Check all possible denominators
for q = 1:M
    % At this q, check all possible numerators
    p0=1;  e0=abs(p0/q - pi);  % best p & error so far
    for p = 1:M
        if abs(p/q - pi) < e0  % new best numerator found
          p0=p;  e0 = abs(p/q - pi);
        end
    end
    % Is best quotient for this q the best overall?
    if e0 < err_pq
        pBest=p0;  qBest=q; err_pq=e0;
    end
end
myPi = pBest/qBest;
```

<u>Algorithm: Finding the best in a set</u>

```
Init bestSoFar
Loop over set
    if current is better than bestSoFar
        bestSoFar ← current
    end
end
```

Analyzing cost

- See Eg3_1 and FasterEg3_1 in the book

```
for a = 1:n
    disp('alpha')
    for b = 1:m
        disp('beta')
    end
end
```

How many times are "alpha" and "beta" displayed?

A: n, m

B: m, n

C: n, n+m

D: n, n*m

E: m*n, m

nestedLoops.m

The savvy programmer…

- Learns useful programming patterns and use them where appropriate
- Seeks inspiration by working through test data "by hand"
  - Asks, "What am I doing?" at each step
  - Sets up a variable for each piece of information maintained when working the problem by hand
- Decomposes the problem into manageable subtasks
  - Refines the solution iteratively, solving simpler subproblems first
- Remembers to check the problem's boundary conditions
- Validates the solution (program) by trying it on test data

Stepping back… what do we know about scripts?

- Bundle complicated logic conveniently under one name
  - To find best rational approx. to π, just run `piFrac`
- Inputs and outputs interact with humans
  - `input(), fprintf()`
- Share variables in common workspace
  - Danger: inheriting bad initialization from previous computation

What if…

- Inputs and outputs interacted with other code?
  - Interaction with humans considered a "side effect"
- Behavior not affected by other computations?

Built-in functions

- We've used many Matlab built-in functions, e.g., `rand()`, `abs()`, `floor()`, `rem()`
- Example: `abs(x-0.5)`
- Observations:
  - `abs()` is set up to be able to work with any valid data
  - `abs()` *doesn't prompt us for input; it expects that we provide data* that it'll then work on
  - `abs()` *returns* a value that we can use in our program

```
yDistance= abs(y2-y1);
```

```
while  abs(myPi-pi) > .0001
    ...
```

User-defined functions

We can write our own functions to perform a specific task:

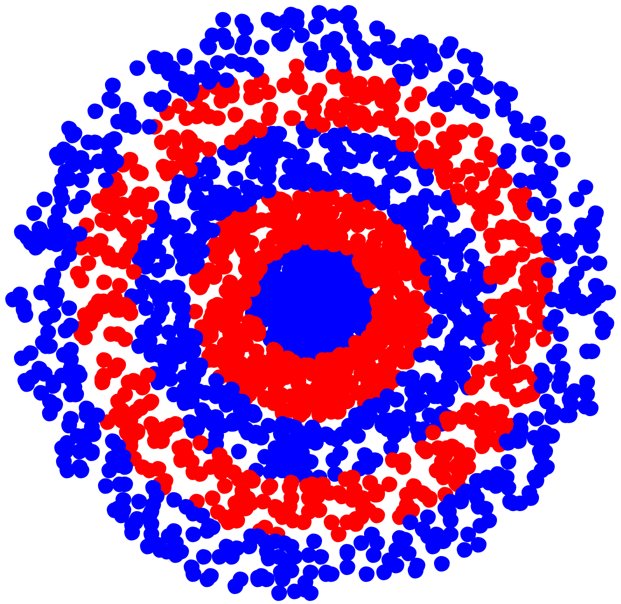
- Example: draw a disk with specified radius, color, and center coordinates
  - Inputs: center, radius, color
  - Outputs: none
  - Side effects: Shows disk to user
- Example: generate a random floating point number in a specified interval
  - Inputs: interval lower bound, interval upper bound
  - Outputs: random number
- Example: convert polar coordinates to x-y (Cartesian) coordinates
  - Inputs: r-coordinate, θ-coordinate
  - Outputs: x-coordinate, y-coordinate

Multiple outputs are allowed!

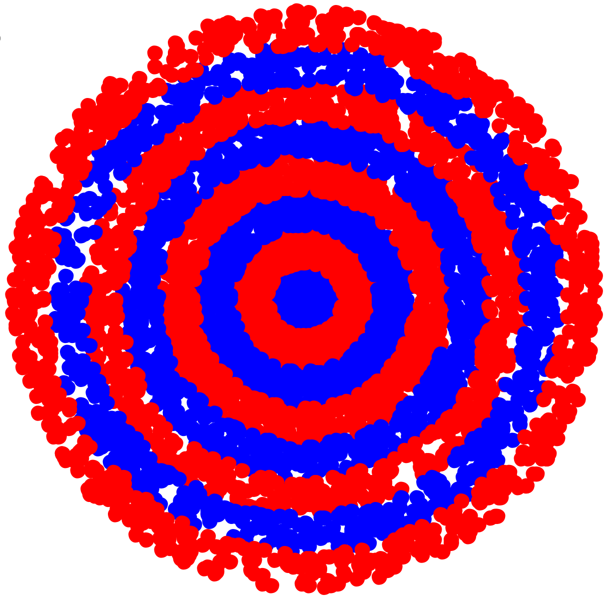
Functions step-by-step

1. Identify candidates
   - Look for opportunities to reuse logic or improve clarity
2. Design interface
   - Name, inputs, outputs, side effects
3. Implement function
   - “Write code”
4. Test
   - Try it out (and try to break it)
5. Use

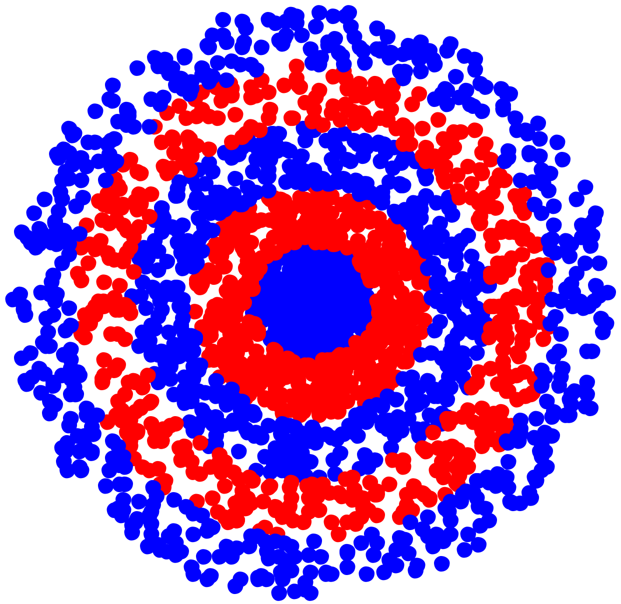
Draw a bulls eye figure with randomly placed dots



- Dots are randomly placed within concentric rings
- User decides how many rings, how many dots per ring



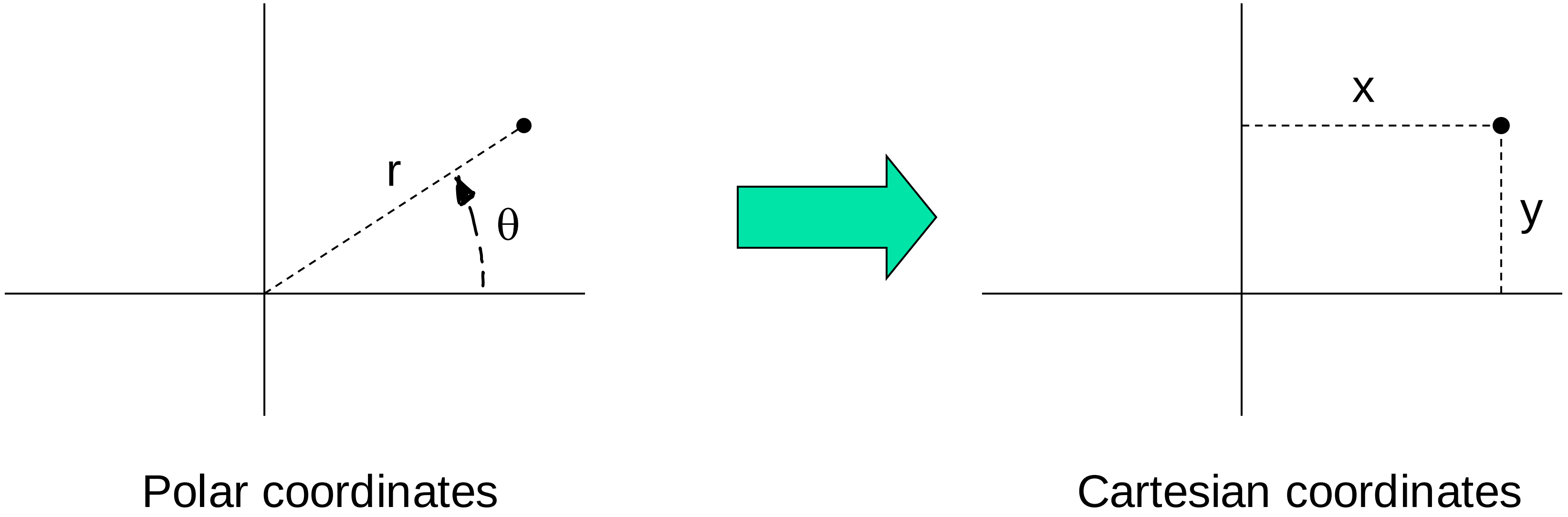
Draw a bulls eye figure with randomly placed dots



- What are the main tasks?
- Accommodate variable number of rings—loop

- For each ring
  - Need many dots (another loop)
  - For each dot
    - Generate random position
    - Choose color
    - Draw it

Convert from polar to Cartesian coordinates



```
c= input('How many concentric rings? ');
d= input('How many dots? ');

% Put dots btwn circles with radii rRing and (rRing-1)
for rRing= 1:c
  % Draw d dots
  for count= 1:d

    % Generate random dot location (polar coord.)
    theta= _______
    r= _______

    % Convert from polar to Cartesian
    x= _______
    y= _______

    % Use plot to draw dot
  end
end
```

A common task! Create a function **polar2xy** to do this. **polar2xy** likely will be useful in other problems as well.

Outline

- For each ring
  - For each dot
    - Generate random position
    - Choose color
    - Draw dot

```
% Generate random dot location (polar)
theta= _____     % degrees
r= _________

% Convert from polar to Cartesian
rads= theta*pi/180;   % radian
x= r*cos(rads);
y= r*sin(rads);
```

Not our job!

Part of a script

```
function [x, y] = polar2xy(r,theta)
% Convert polar coordinates (r,theta) to
% Cartesian coordinates (x,y).
% theta is in degrees.

rads= theta*pi/180;  % radian
x= r*cos(rads);
y= r*sin(rads);
```

A function file

polar2xy.m

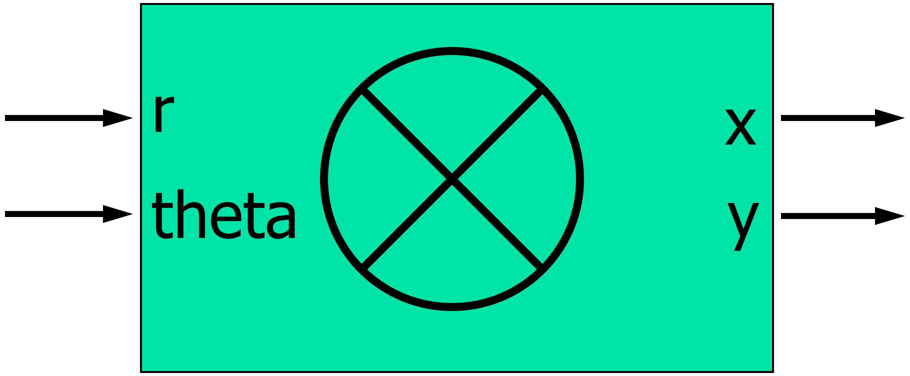
```
function [x, y] = polar2xy(r,theta)
% Convert polar coordinates (r,theta) to
% Cartesian coordinates (x,y).
% theta is in degrees.

rads= theta*pi/180;   % radian
x= r*cos(rads);
y= r*sin(rads);
```

A function file `polar2xy.m`

Think of `polar2xy` as a factory

Caller provides input to the "factory"



"Factory" produces output for caller to use

```
function [x, y] = polar2xy(r,theta)
% Convert polar coordinates (r,theta) to
% Cartesian coordinates (x,y).
% theta is in degrees.

rads= theta*pi/180;   % radian
x= r*cos(rads);
y= r*sin(rads);
```

A function file **polar2xy.m**

```
r= input('Enter radius: ');
theta= input('Enter angle in degrees: ');

rads= theta*pi/180;   % radian
x= r*cos(rads);
y= r*sin(rads);
```

(Part of) a script file

Functions step-by-step

1. Identify candidates
   - Look for opportunities to reuse logic or improve clarity
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   - Name, inputs, outputs, side effects
3. Implement function
   - “Write code”
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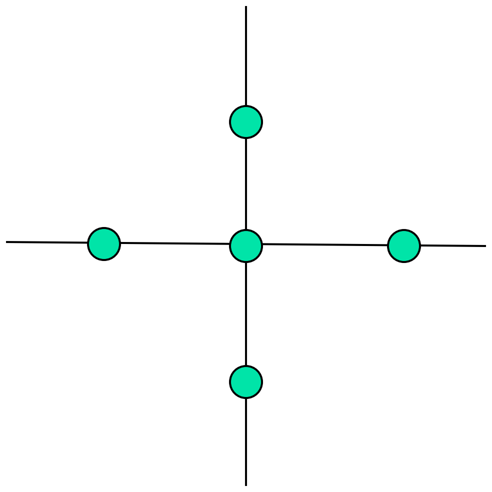
   - Try it out (and try to break it)
5. Use

Time for testing

- Good test cases:
  - `r = 0`
  - `theta = 0, pi/2, pi, 3*pi/2`
  - `theta = -pi, 3*pi`
- How to test
  - `[x, y]= polar2xy(r, theta)`
  - Command window
  - Test script
  - DON'T try to "run" the function file



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  for count= 1:d

    % Generate random dot location (polar coord.)
    theta= _______
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    % Convert from polar to Cartesian
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% Put dots btwn circles with radii rRing and (rRing-1)
for rRing= 1:c
  % Draw d dots
  for count= 1:d

    % Generate random dot location (polar coord.)
    theta= _______
    r= _______

    % Convert from polar to Cartesian
    x= _______
    y= _______                [x,y] = polar2xy(r,theta);

    % Use plot to draw dot
  end
end
```

```
function [x, y] = polar2xy(r,theta)
```

Output parameter list enclosed in [ ]

Function name (This file's name is `polar2xy.m`)

Input parameter list enclosed in ( )

Function header is the "contract" for how the function will be used (called)

You have this function:

```
function  [x, y] = polar2xy(r, theta)
% Convert polar coordinates (r, theta) to
% Cartesian coordinates (x,y).  Theta in degrees.
…
```

Code to call the above function:

```
% Convert polar (r1,t1) to Cartesian (x1,y1)
r1= 1;  t1= 30;
[x1, y1]= polar2xy(r1, t1);
plot(x1, y1, 'b*')
…
```

Function header is the “contract” for how the function will be used (called)

You have this function:

```
function [x, y] = polar2xy(r, theta)
% Convert polar coordinates (r,theta) to
% Cartesian coordinates (x,y). Theta in degrees.
…
```

Code to call the above function:

```
% Convert polar (r1,t1) to Cartesian (x1,y1)
r1= 1; t1= 30;
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```