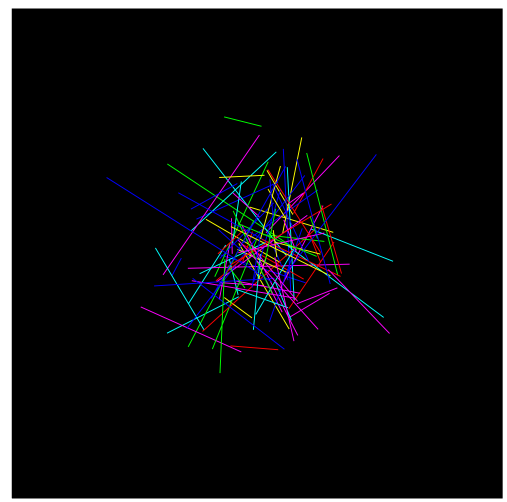
- Previous Lecture:
  - File I/O, use of cell array
- Today's Lecture:
  - Structures
  - Structure array (i.e., an array of structures)
  - A structure with array fields
- Announcements:
  - Discussion this week in classrooms, not lab
  - Project 5 due Thurs 11/3 at 11pm. Reduced late penalty of 5% applies to submission made up to 11/4 at 11pm
  - TA Jeannie will hold an extra office hour this Friday 4:30-5:30pm. Location TBA.
  - Prelim 2 on Thurs 11/10 at 7:30pm. Email Randy Hess (rbh27) now if you have an exam conflict (include the course and instructor info of the conflicting exam)

Data are often related

- A point in the plane has an x coordinate and a y coordinate.
- If a program manipulates lots of points, there will be lots of x's and y's.
- Anticipate clutter. Is there a way to "package" the two coordinate values?



Packaging affects thinking

Our Reasoning Level:

P and Q are points. Compute the midpoint M of the connecting line segment.

Behind the scenes we do this:

$$M_x = (P_x + Q_x)/2$$
$$M_y = (P_y + Q_y)/2$$

We've seen this before: functions are used to "package" calculations.

This packaging (a type of abstraction) elevates the level of our reasoning and is critical for problem solving.

Options for storing a point (-4, 3.1)

- Simple scalars — `xdat` -4 `ydat` 3.1 — *Ungrouped data*

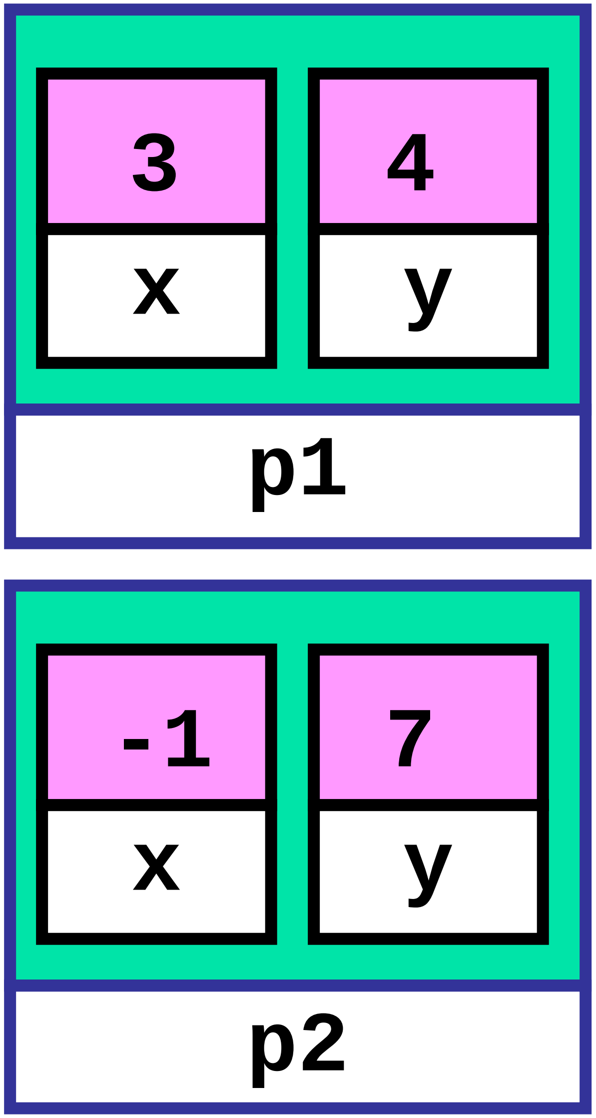
- Simple vector — `ptdat` [1: -4, 2: 3.1]
- Cell array — `ptdatc {` [1: -4] [2: 3.1] `}`

Related data grouped into an array. X-coord implicitly labelled 1; y-coord implicitly labelled 2

- Struct — `pt` [x: -4, y: 3.1] — *Related data grouped into a struct variable. Explicit, clear labelling is possible via field names*

Example: a Point structure

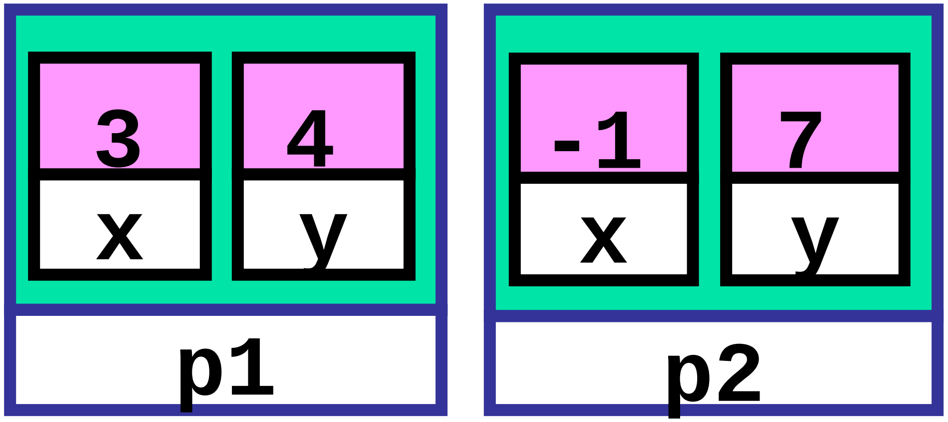
```
% p1 is a Point
p1.x= 3;
p1.y= 4;

% p2 is another Point
p2.x= -1;
p2.y= 7;
```



A Point has two properties—fields—x and y

Working with Point structures

```
p1.x=3;  p1.y=4;
p2.x=-1; p2.y=7;
```

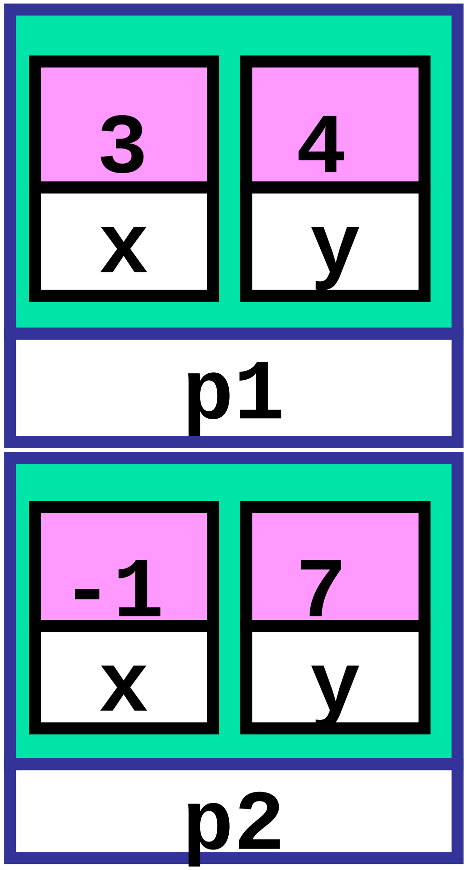



```
% Distance between points p1 and p2
D= sqrt((p1.x-p2.x)^2 + (p1.y-p2.y)^2);
```

Note that **p1.x, p1.y, p2.x, p2.y** participate in the calculation as variables—because they are.

Different ways to create a structure

```
% Create a struct by assigning field values
p1.x= 3;
p1.y= 4;
% Create a struct with built-in function
p2 = struct('x',-1, 'y',7);
```



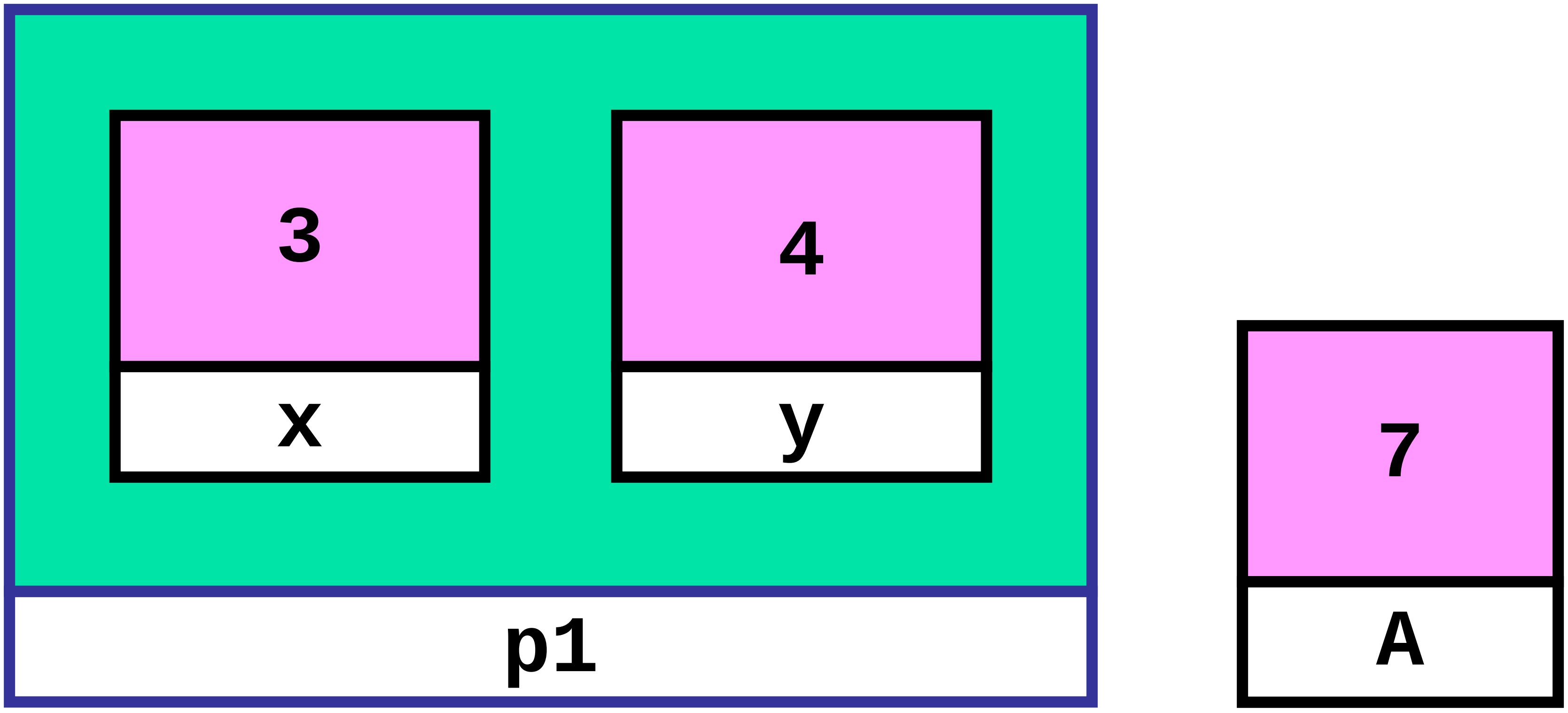
p2 is a structure.

The structure has two fields.

Their names are **x** and **y**.

They are assigned the values -1 and 7.

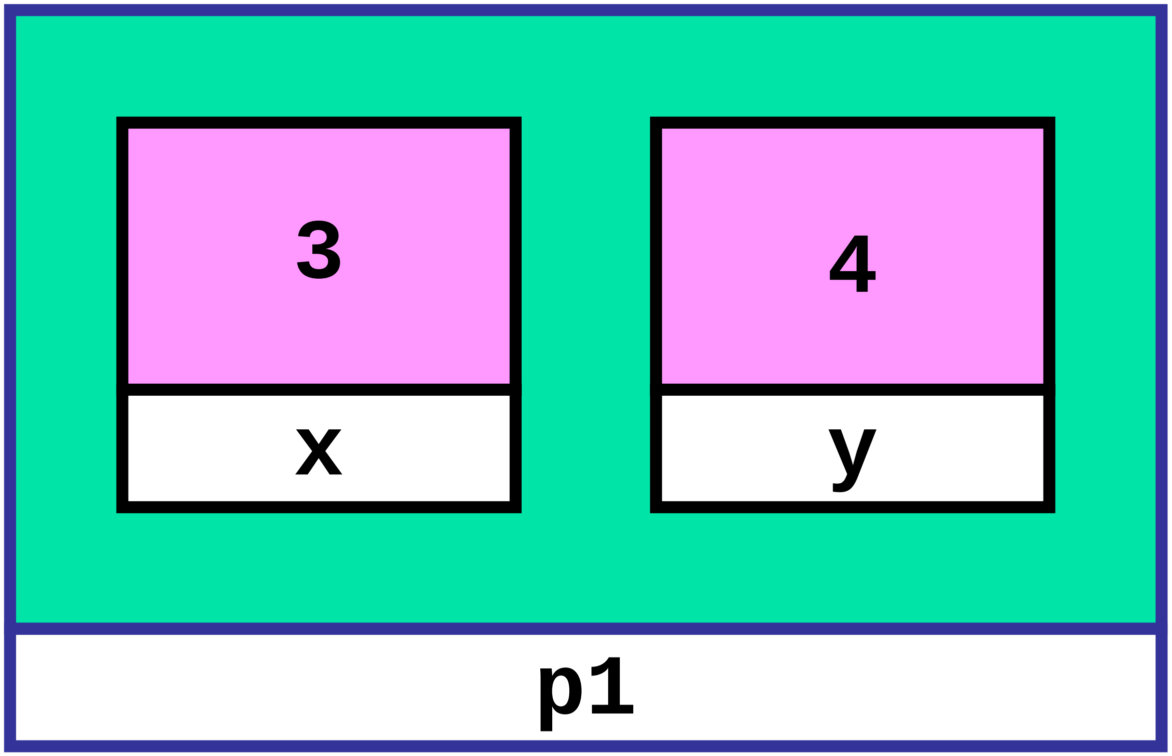
Accessing the fields in a structure




```
A = p1.x + p1.y;
```

Assigns the value 7 to A

Assigning to a field in a structure




```
p1.x = p1.y^2;
```

Assigns the value 16 to p1.x

A structure can have fields of different types

```
A = struct('sname', 'New York',…
           'capital', 'Albany',…
           'pop', 15.5)
```

- Can have combinations of string fields and numeric fields
- Arguments are given in pairs: a field name, followed by the value

Legal/Illegal maneuvers

```
Q = struct('x',5,'y',6)

R = Q           % Legal. R is a copy of Q

S = (Q+R)/2     % Illegal. Must access the
                % fields to do calculations

P = struct('x',3,'y') % Illegal. Args must be
                      % in pairs (field name
                      % followed by field
                      % value)

P = struct('x',3,'y',[]) % Legal. Use [] as
P.y = 4                  % place holder
```

Structures in functions

```
function d = dist(P,Q)
% P and Q are points (structure).
% d is the distance between them.

d = sqrt((P.x-Q.x)^2 + ...
         (P.y-Q.y)^2);
```

Example “Make” Function

> Good style: use a “make” function to highlight a structure’s definition

```
function P = MakePoint(x,y)
% P is a point with P.x and P.y
% assigned the values x and y.

P = struct('x',x,'y',y);
```

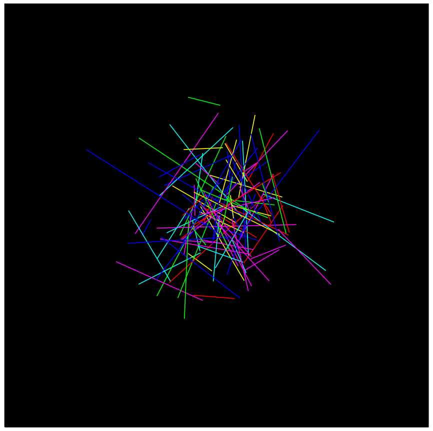
Then in a script or some other function…

```
a= 10;  b= rand;
Pt= MakePoint(a,b); % create a point struct
                    % according to definition
                    % in MakePoint function
```

Another function that has structure parameters

```
function DrawLine(P,Q,c)
% P and Q are points (structure).
% Draws a line segment connecting
% P and Q. Color is specified by c.

plot([P.x Q.x],[P.y Q.y],c)
```

Pick Up Sticks

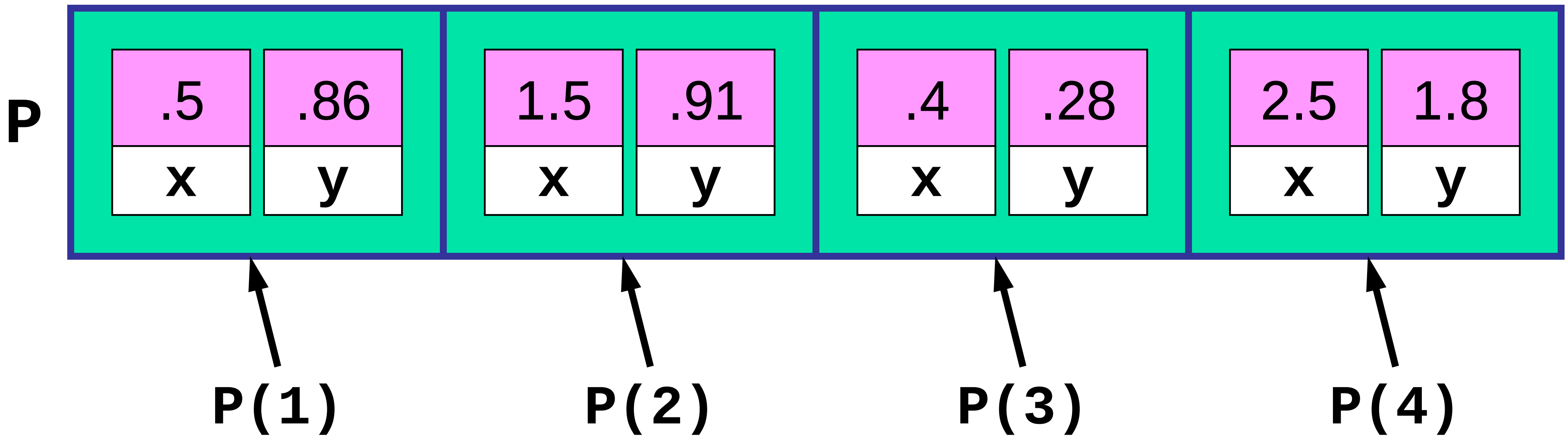


```
s = 'rgbmcy';
for k=1:100
   P = MakePoint(randn,randn);
   Q = MakePoint(randn,randn);
   c = s(ceil(6*rand));
   DrawLine(P,Q,c)
end
```

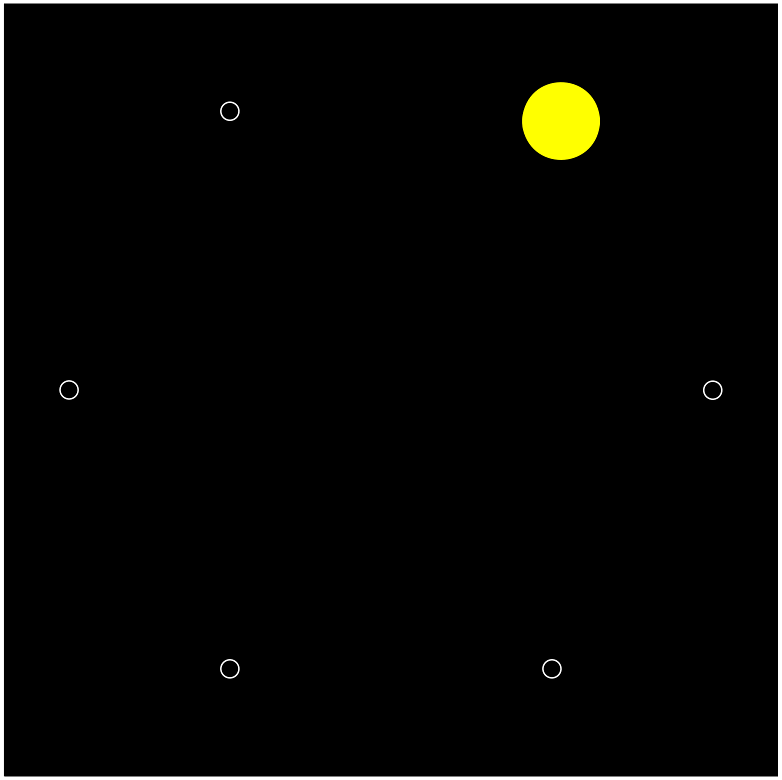
Generates two random points and connect them using one of six colors chosen randomly.

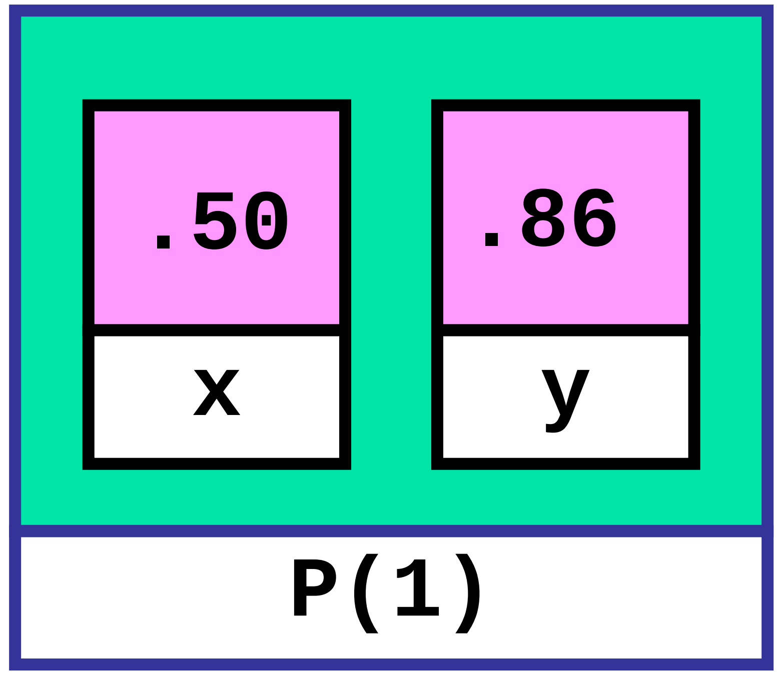
Structure Arrays

- An array whose components are structures
- All the structures must be the same (have the same fields) in the array
- Example: an array of points (point structures)



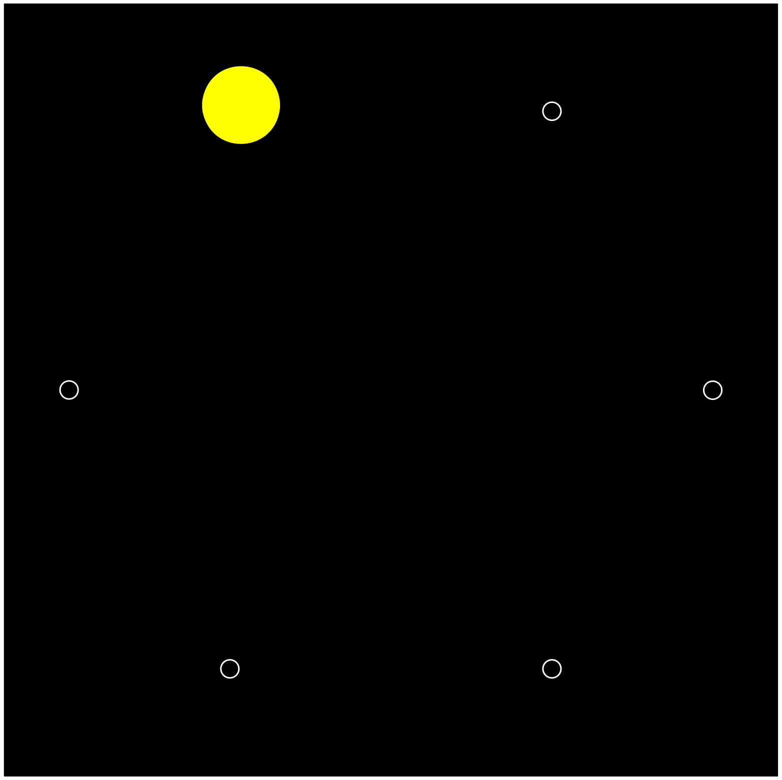
An Array of Points

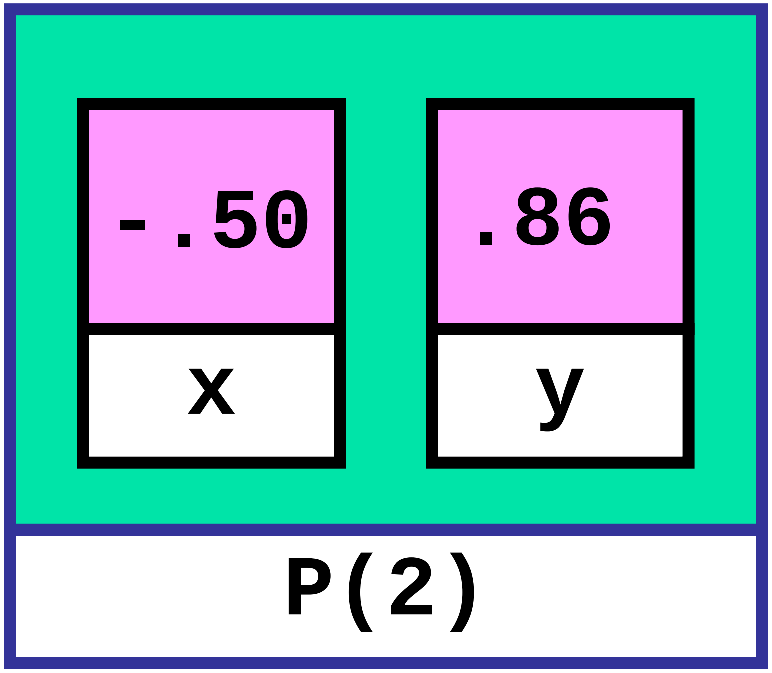




P(1) = MakePoint(.50,.86)

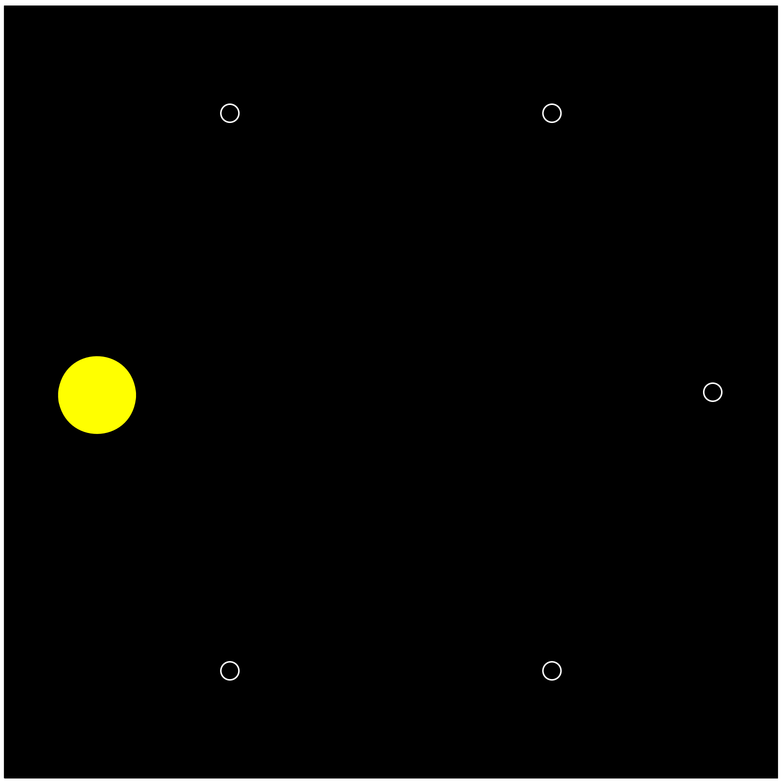
An Array of Points

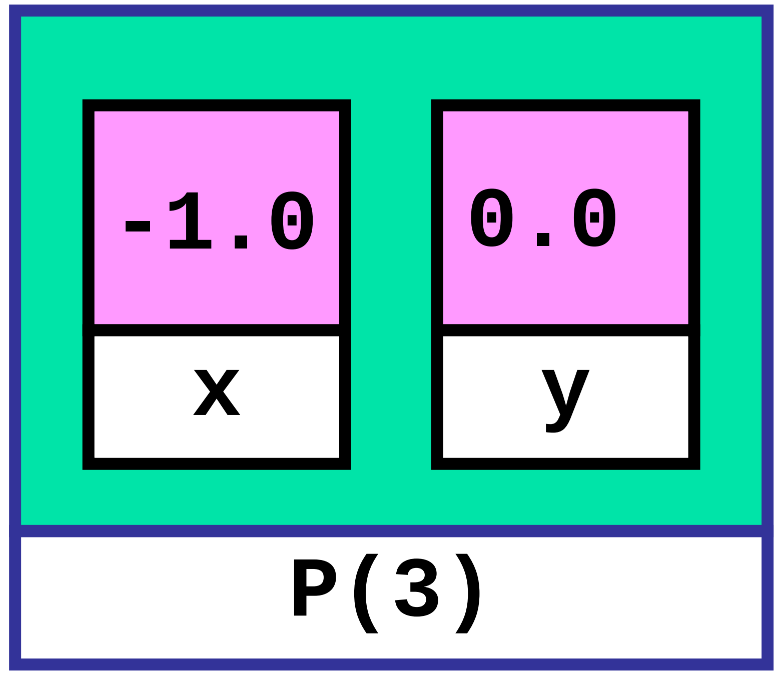




`P(2) = MakePoint(-.50,.86)`

An Array of Points






```
P(3) = MakePoint(-1.0,0.0)
```

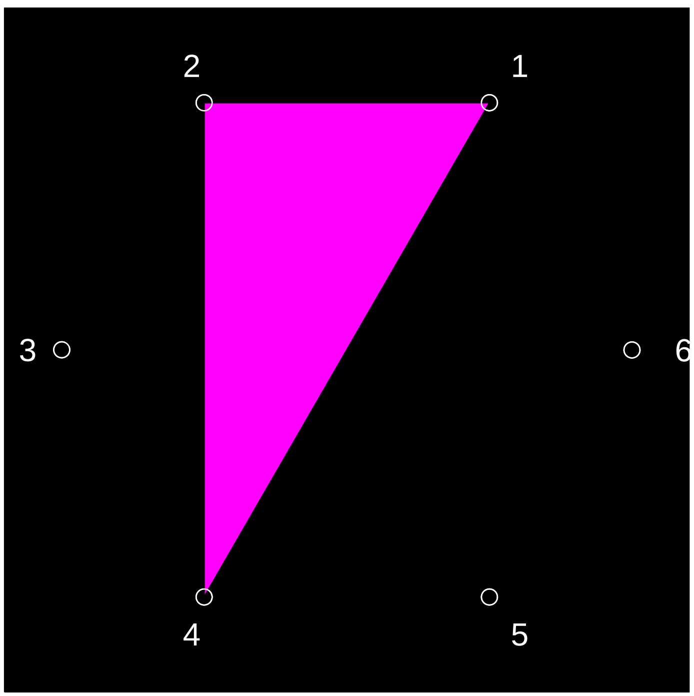
Function returning an array of points (point structures)

```
function P = CirclePoints(n)
%P is array of n point structs; the
%points are evenly spaced on unit circle

 theta = 2*pi/n;
 for k=1:n
    c = cos(theta*k);
    s = sin(theta*k);
    P(k) = MakePoint(c,s);
 end
```

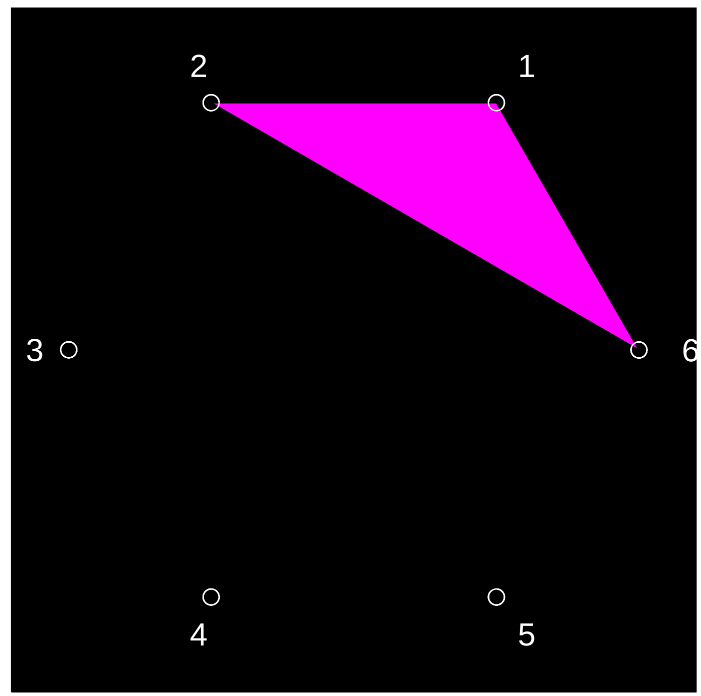
Example: all possible triangles

- Place n points uniformly around the unit circle.
- Draw all possible unique triangles obtained by connecting these points 3-at-a-time.

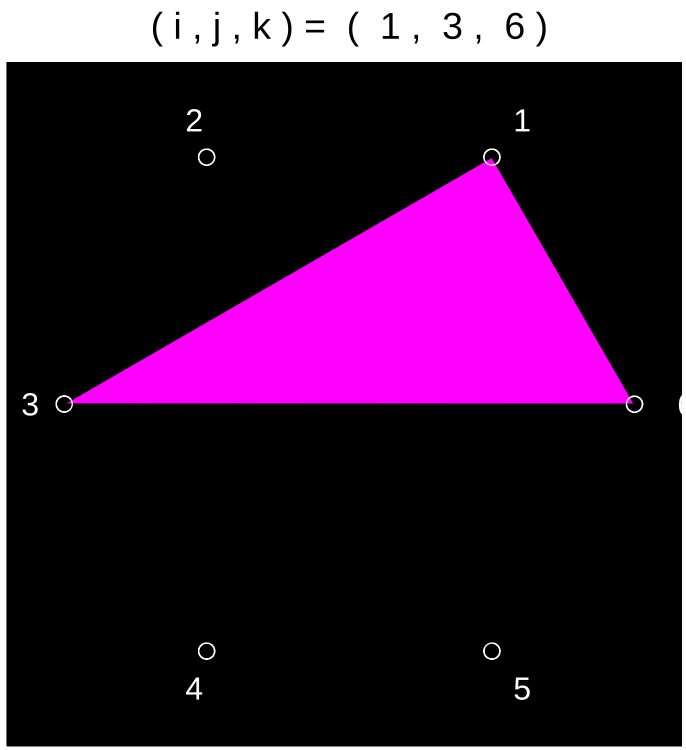
(i,j,k) = (1, 2, 4)

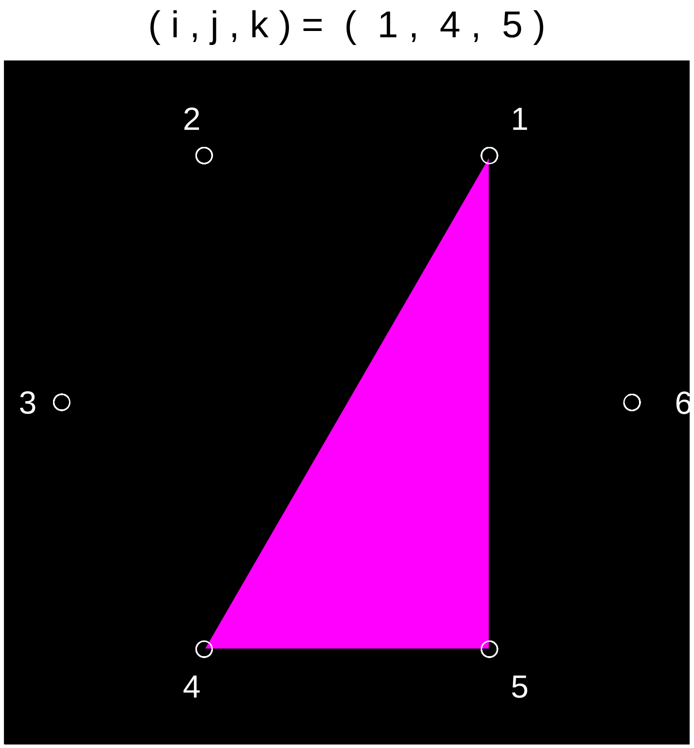


(i,j,k) = (1, 2, 6)



```matlab
function DrawTriangle(U,V,W,c)
% Draw c-colored triangle;
% triangle vertices are points U,
% V, and W.

fill([U.x V.x W.x], ...
     [U.y V.y W.y], c)
```





The following triangles are the same: (1,3,6), (1,6,3), (3,1,6), (3,6,1), (6,1,3), (6,3,1)

Bad! i, j, and k should be different, and there should be no duplicates

```
% Given P, an array of point structures
for i=1:n
  for j=1:n
    for k=1:n
       DrawTriangle(P(i),P(j),P(k),'m')
       pause
       DrawTriangle(P(i),P(j),P(k),'k')
    end
   end
end
```

All possible (i,j,k) combinations but avoid duplicates.

Loop index values have this relationship i < j < k

i j k

i = 1	i = 2	i = 3	i = 4
1 2 3	2 3 4	3 4 5	4 5 6
1 2 4	2 3 5	3 4 6	
1 2 5	2 3 6	3 5 6	
1 2 6	2 4 5		
1 3 4	2 4 6		
1 3 5	2 5 6		
1 3 6			
1 4 5			
1 4 6			
1 5 6			

```
for i=1:n-2
  for j=i+1:n-1
    for k=j+1:n
      disp([i j k])
    end
  end
end
```

All possible (i,j,k) combinations but avoid duplicates. Loop index values have this relationship $i < j < k$

```
for i=1:n-2
  for j=i+1:n-1
    for k=j+1:n
      disp([i j k])
    end
  end
end
```

```
for i=1:n
  for j=1:n
    for k=1:n
      if i<j && j<k
        disp([i j k])
      end
    end
  end
end
```

Both versions print all possible, unique combinations of (i,j,k), but the left fragment is far more efficient

All possible (i,j,k) combinations but avoid duplicates.
Loop index values have this relationship $i < j < k$

```
for i=1:n-2
  for j=i+1:n-1
    for k=j+1:n
      % Draw triangle with
      % vertices P(i),P(j),P(k)
    end
  end
end
```

All possible unique triangles

```
% Drawing on a black background
for i=1:n-2
  for j=i+1:n-1
    for k=j+1:n
      DrawTriangle( P(i),P(j),P(k),'m')
      DrawPoints(P)
      pause
      DrawTriangle(P(i),P(j),P(k),'k')
    end
  end
end
```

See **LotsaTriangles.m**