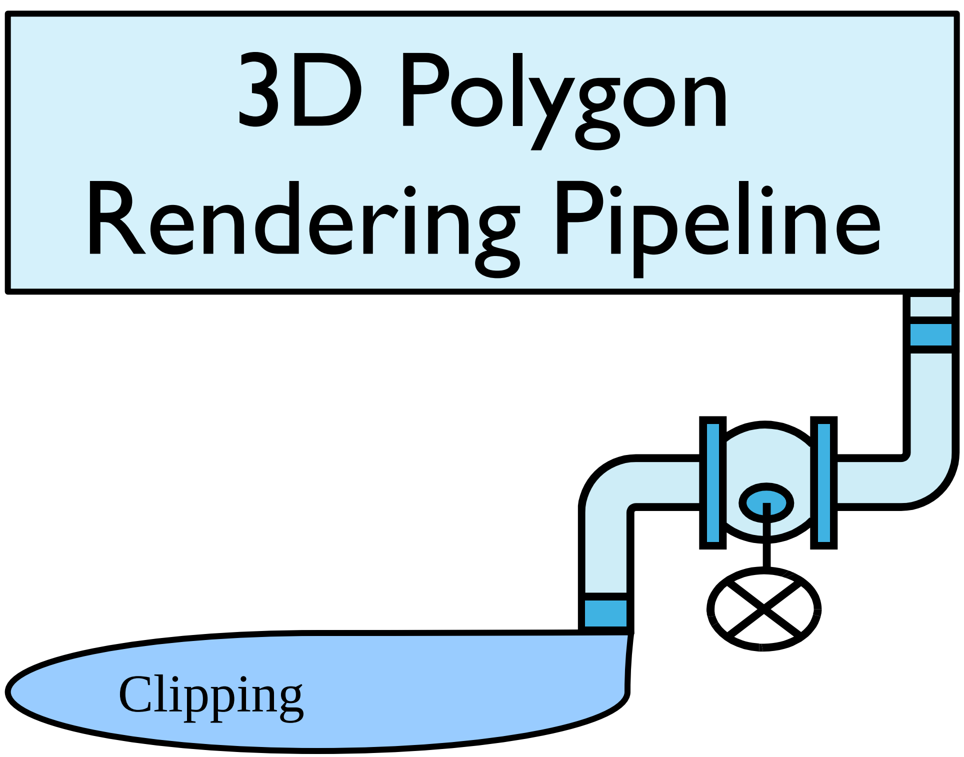
2009/2010 סמסטר א'

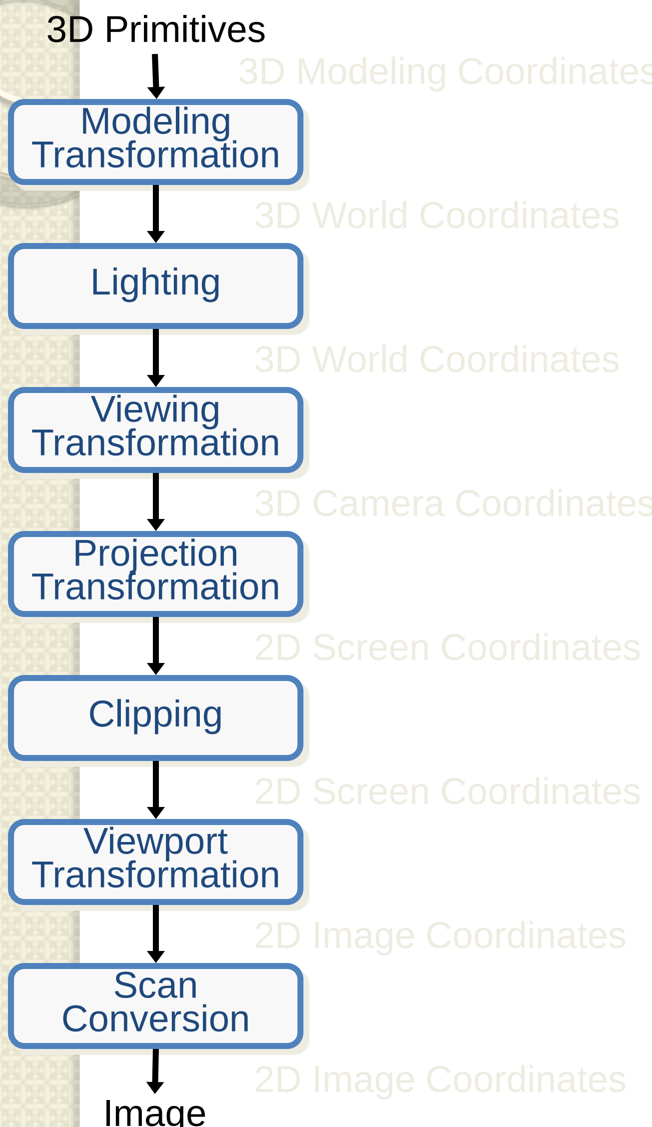
ליאור שפירא

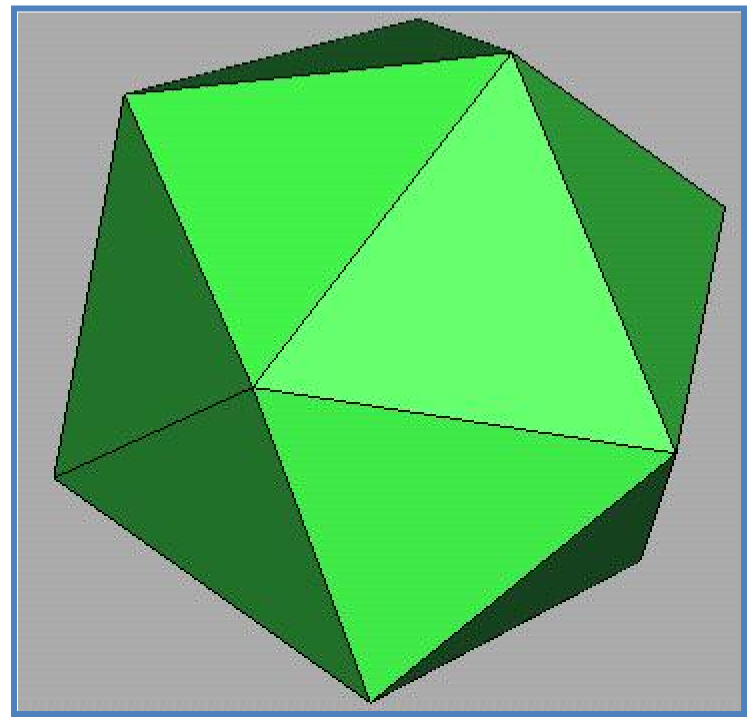
קורס גרפיקה ממוחשבת

שיעור 6



3D Rendering Pipeline (for direct illumination)





3D Rendering Pipeline (for direct illumination)

3D Primitives

3D Modeling Coordinates

Modeling Transformation

3D World Coordinates

Lighting

3D World Coordinates

Viewing Transformation

3D Camera Coordinates

Projection Transformation

2D Screen Coordinates

Clipping

2D Screen Coordinates

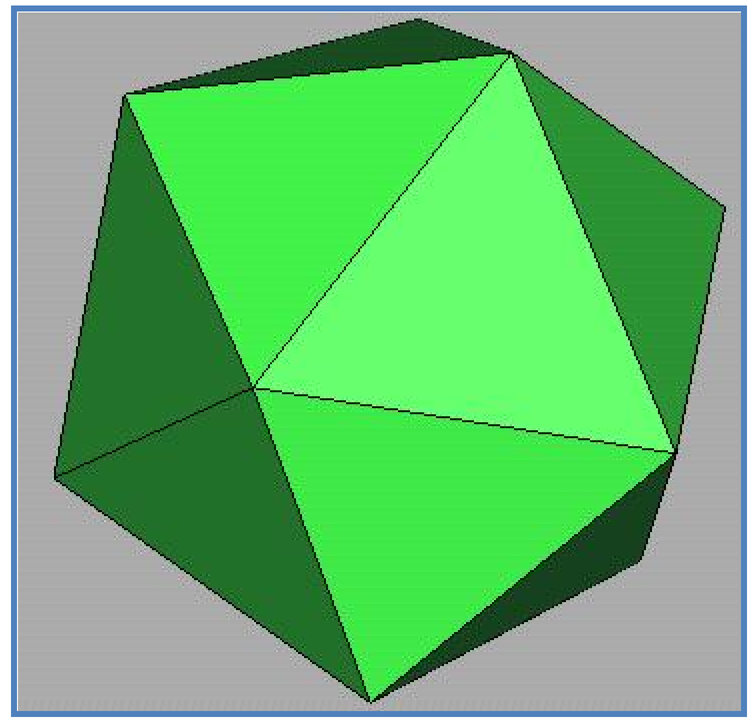
Viewport Transformation

2D Image Coordinates

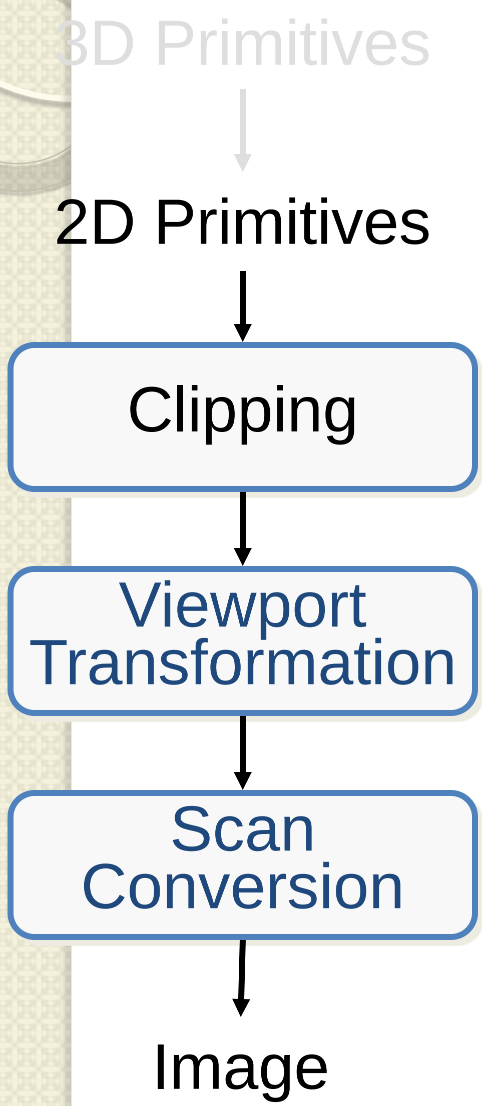
Scan Conversion

2D Image Coordinates

Image



2D Rendering Pipeline

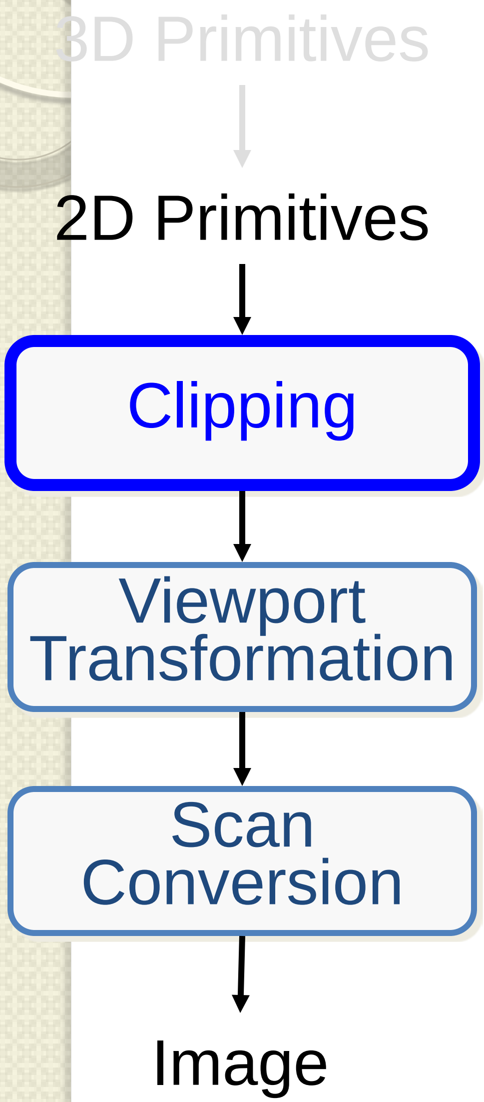


Clip portions of geometric primitives residing outside the window

Transform the clipped primitives from screen to image coordinates

Fill pixels representing primitives in screen coordinates

2D Rendering Pipeline



Clip portions of geometric primitives residing outside the window

Transform the clipped primitives from screen to image coordinates

Fill pixels representing primitives in screen coordinates

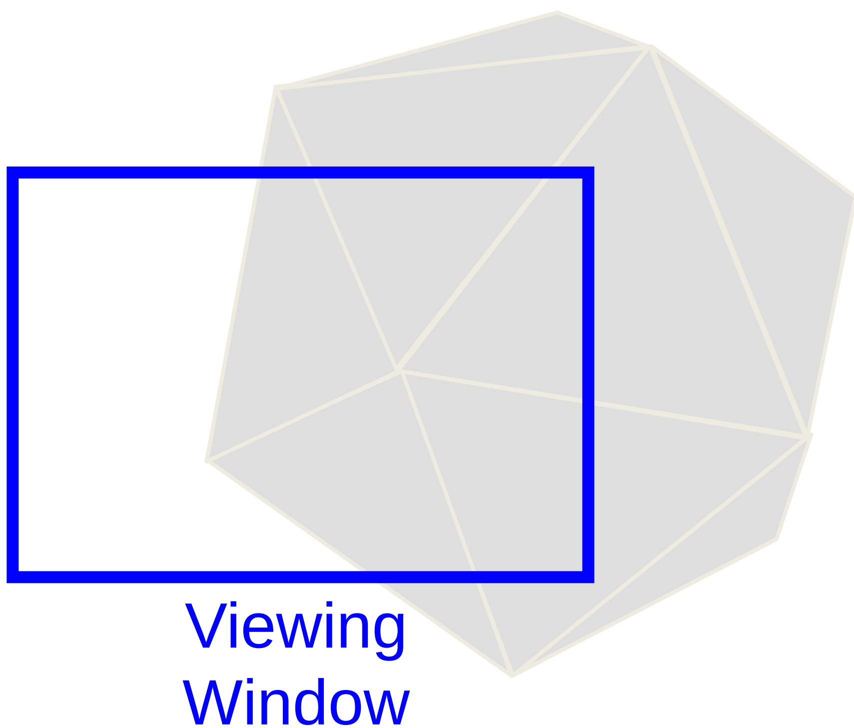
Clipping

- Avoid drawing parts of primitives outside window
  - Window defines part of scene being viewed
  - Must draw geometric primitives only inside window

Screen Coordinates

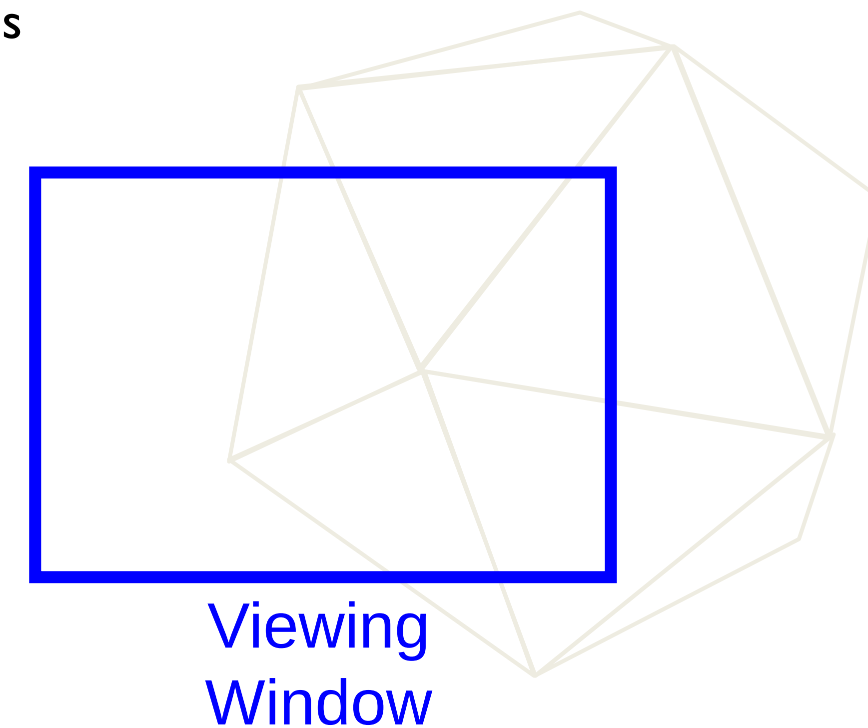
Clipping

- Avoid drawing parts of primitives outside window
  - Window defines part of scene being viewed
  - Must draw geometric primitives only inside window



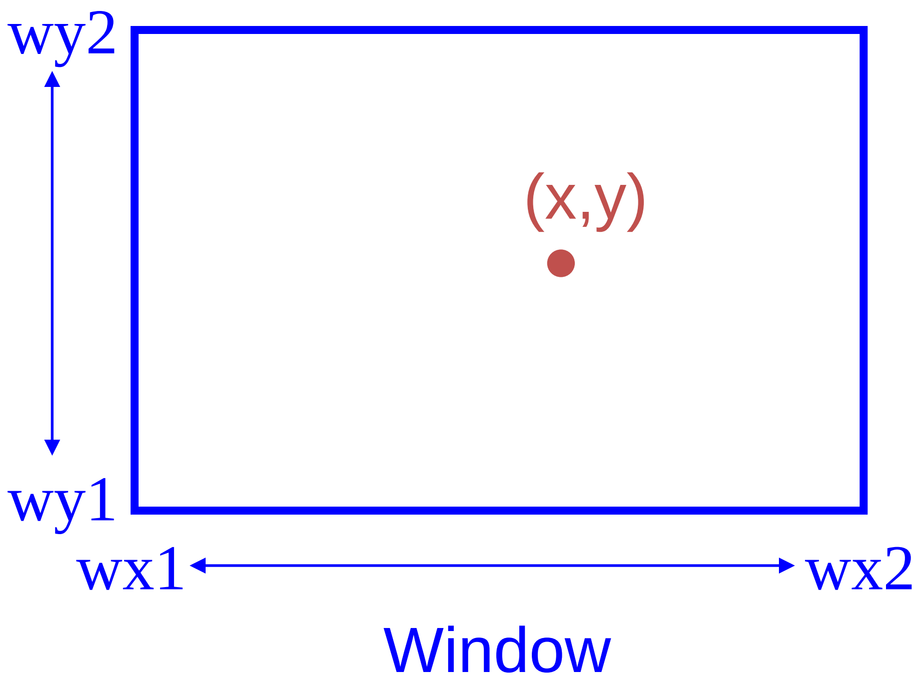
Clipping

- Avoid drawing parts of primitives outside window
  - Points
  - Lines
  - Polygons
  - Circles
  - etc.



Point Clipping

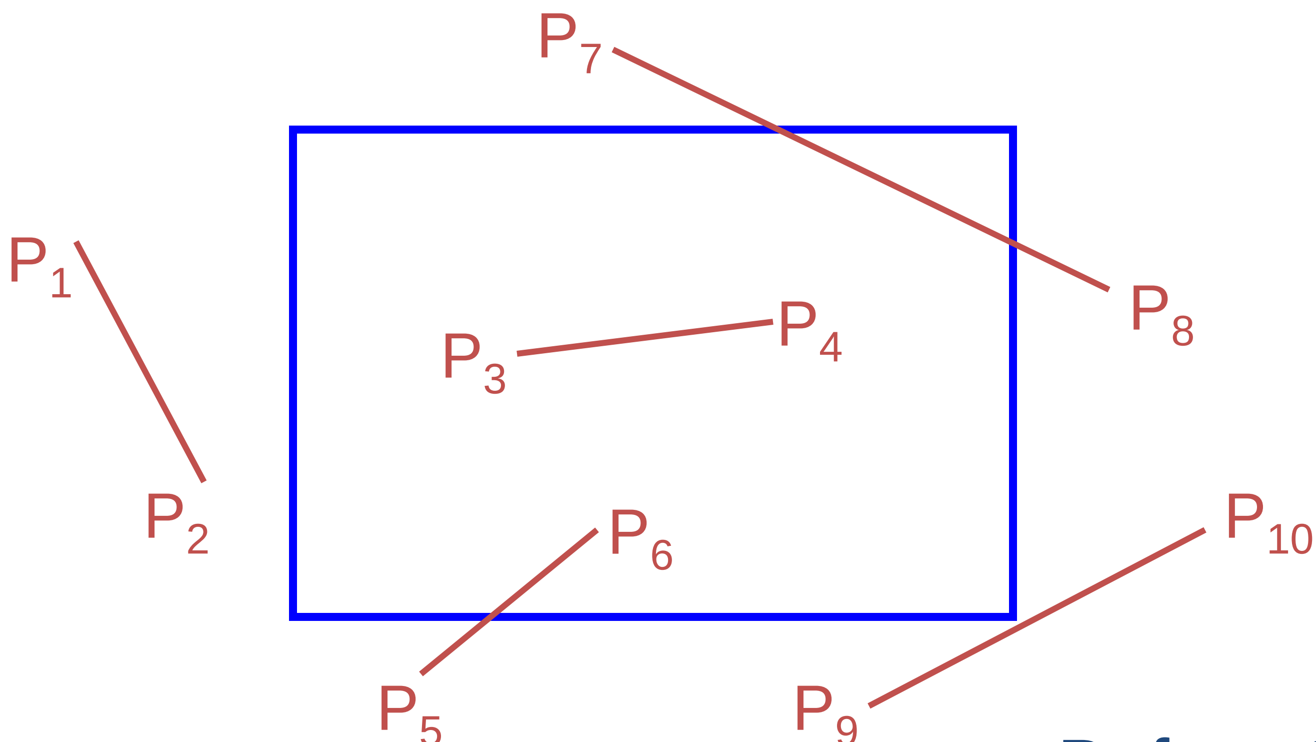
- Is point (x,y) inside the clip window?




```
inside =
   (x >= wx1) &&
   (x <= wx2) &&
   (y >= wy1) &&
   (y <= wy2);
```

Line Clipping

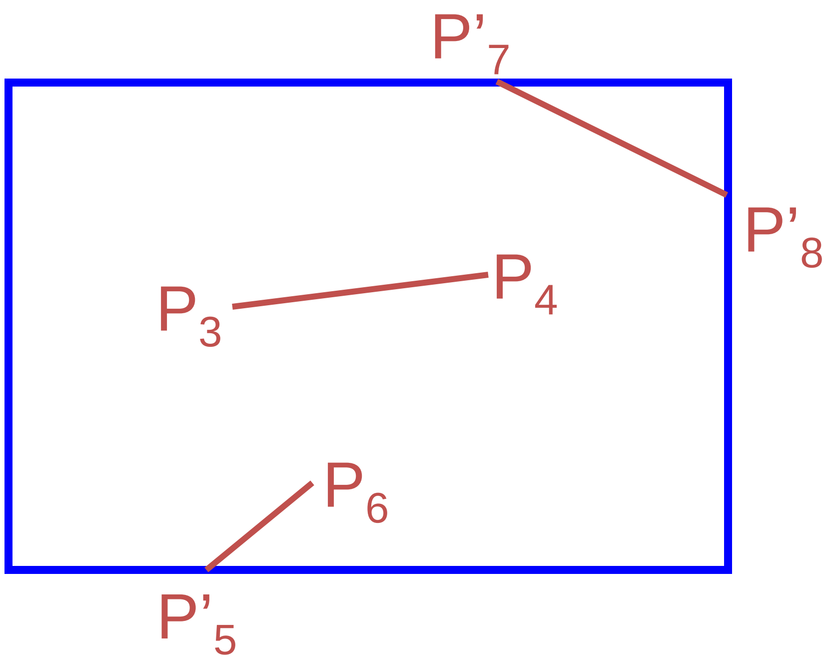
- Find the part of a line inside the clip window



Before Clipping

Line Clipping

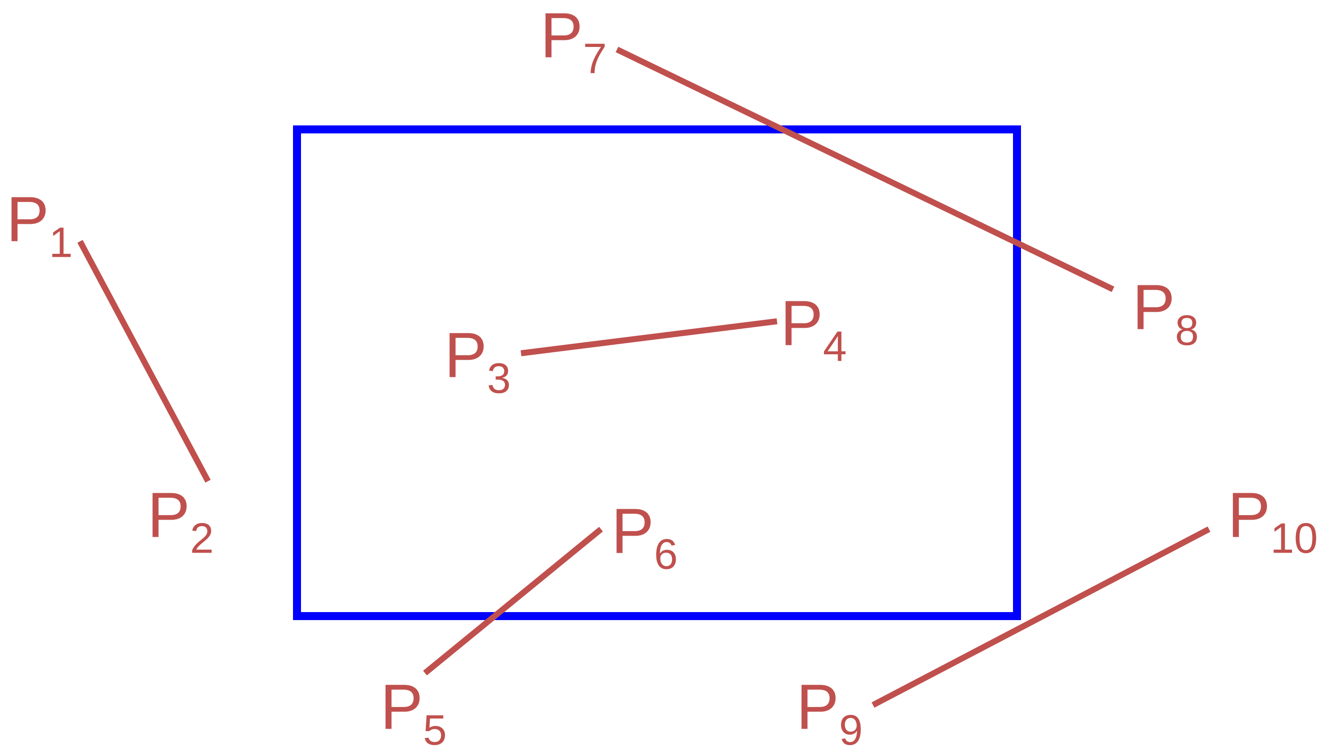
- Find the part of a line inside the clip window



After Clipping

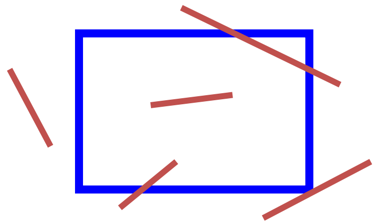
Cohen-Sutherland Line Clipping

- Use simple tests to classify easy cases first



Cohen-Sutherland Line Clipping

- Use simple tests to classify easy cases first

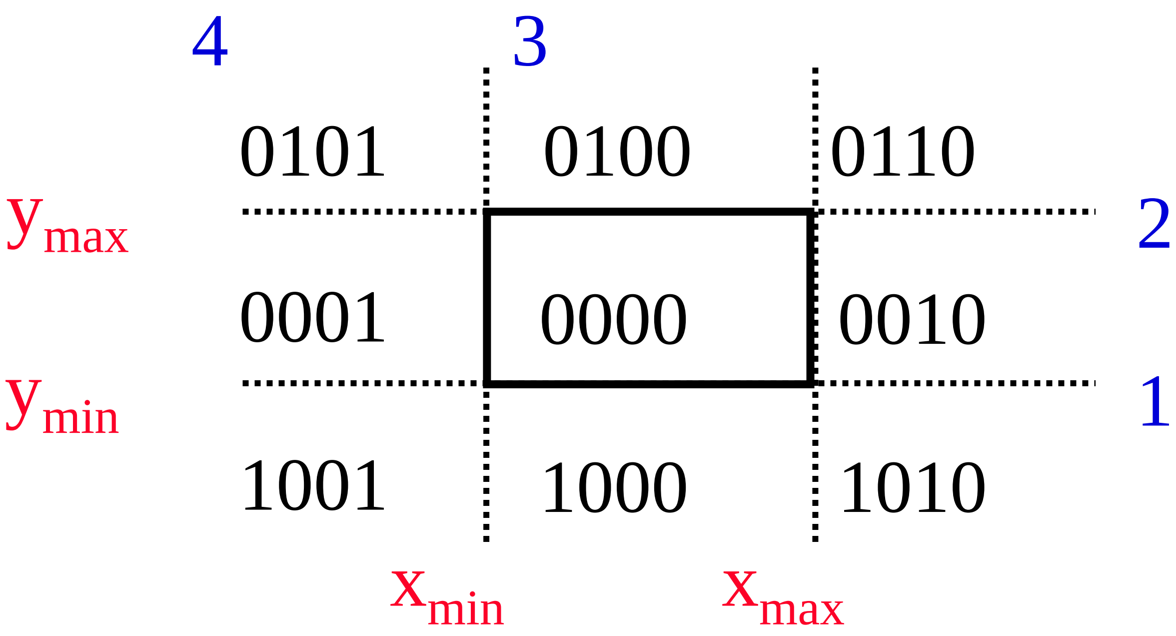


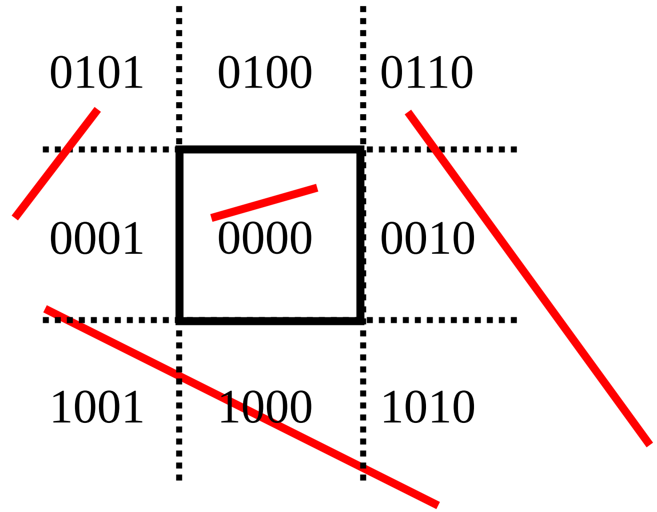
Clipping is performed by the computation of the intersections with four boundary segments of the window: Li,   i=1,2,3,4

Purpose: Fast treatment of lines that are trivially inside/outside the window.
Let P=(x,y) be a point to be classified against window W.

Idea: Assign P a binary code consisting of a bit for each edge of W, whose value is determined according to the following table:

bit	1	0
1	$y < y_{min}$	$y \geq y_{min}$
2	$y > y_{max}$	$y \leq y_{max}$
3	$x > x_{max}$	$x \leq x_{max}$
4	$x < x_{min}$	$x \geq x_{min}$

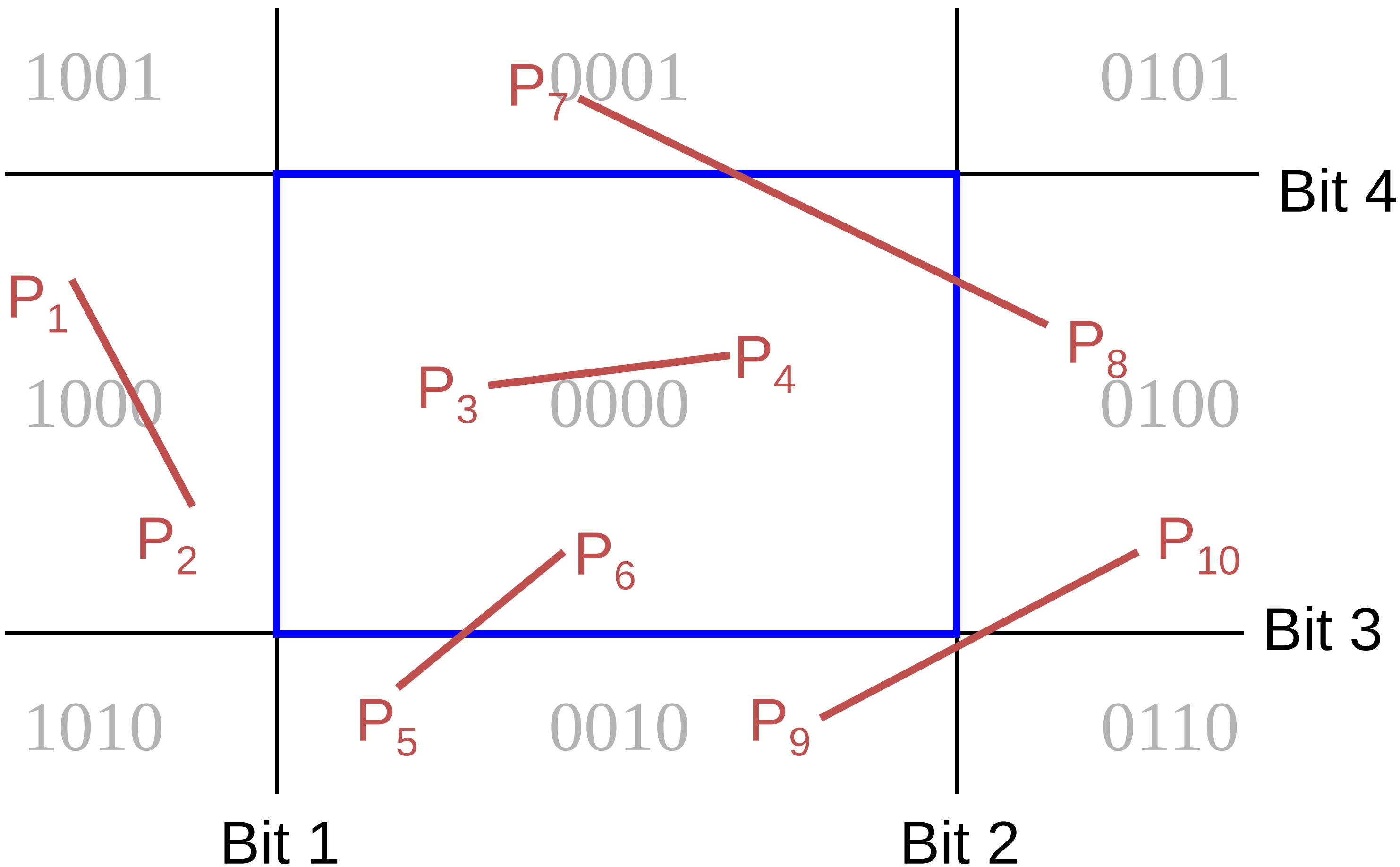




- Given a line segment *S* from $p_0=(x_0,y_0)$ to $p_1=(x_1,y_1)$ to be clipped against a window *W*.
- If code(p_0) **AND** code(p_1) is not zero - then *S* is *trivially rejected*.
- If code(p_0) **OR** code(p_1) is zero - then *S* is *trivially accepted*.

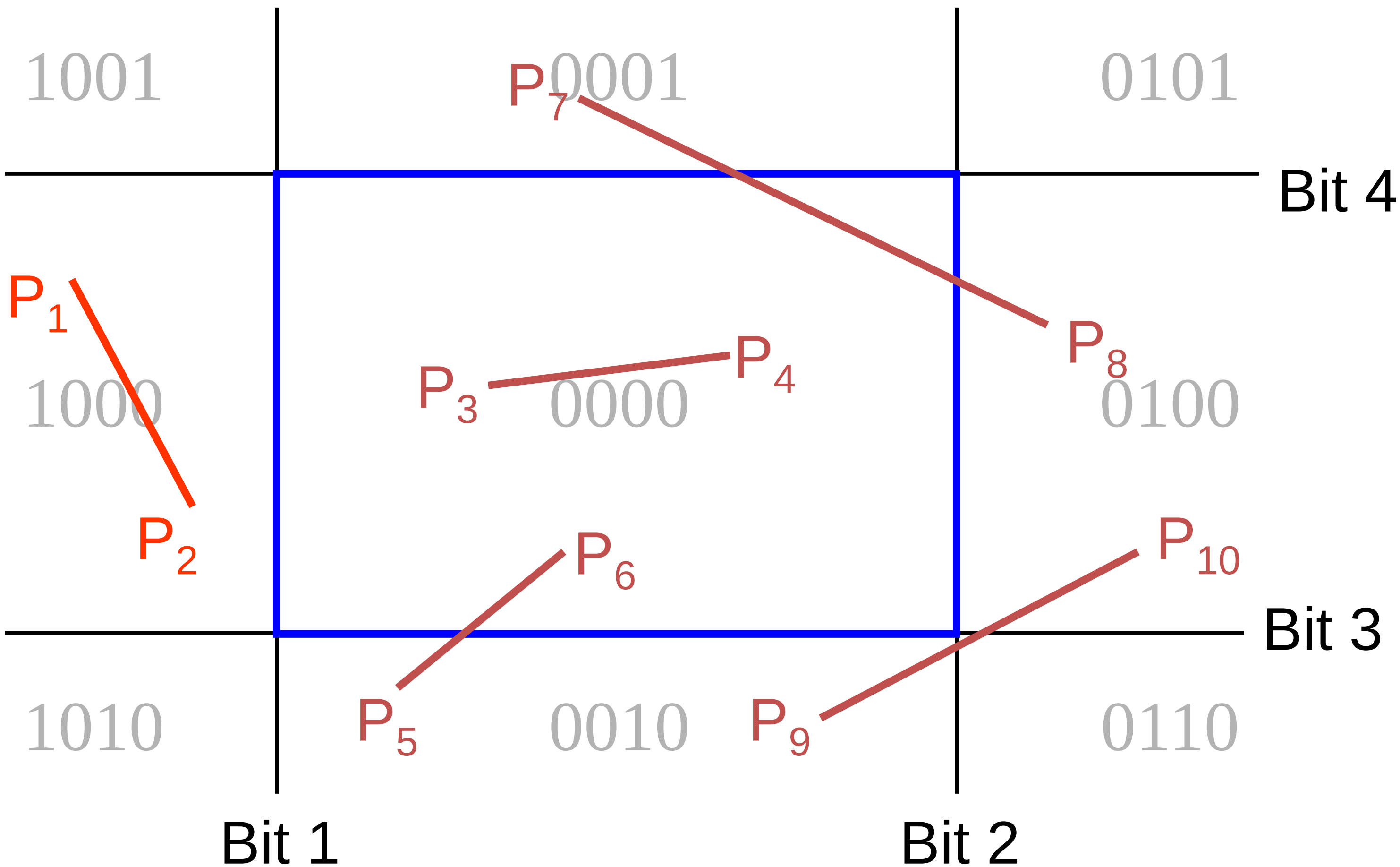
Cohen Sutherland Line Clipping

- Classify some lines quickly by AND of bit codes representing regions of two endpoints (must be 0)



Cohen Sutherland Line Clipping

- Classify some lines quickly by AND of bit codes representing regions of two endpoints (must be 0)



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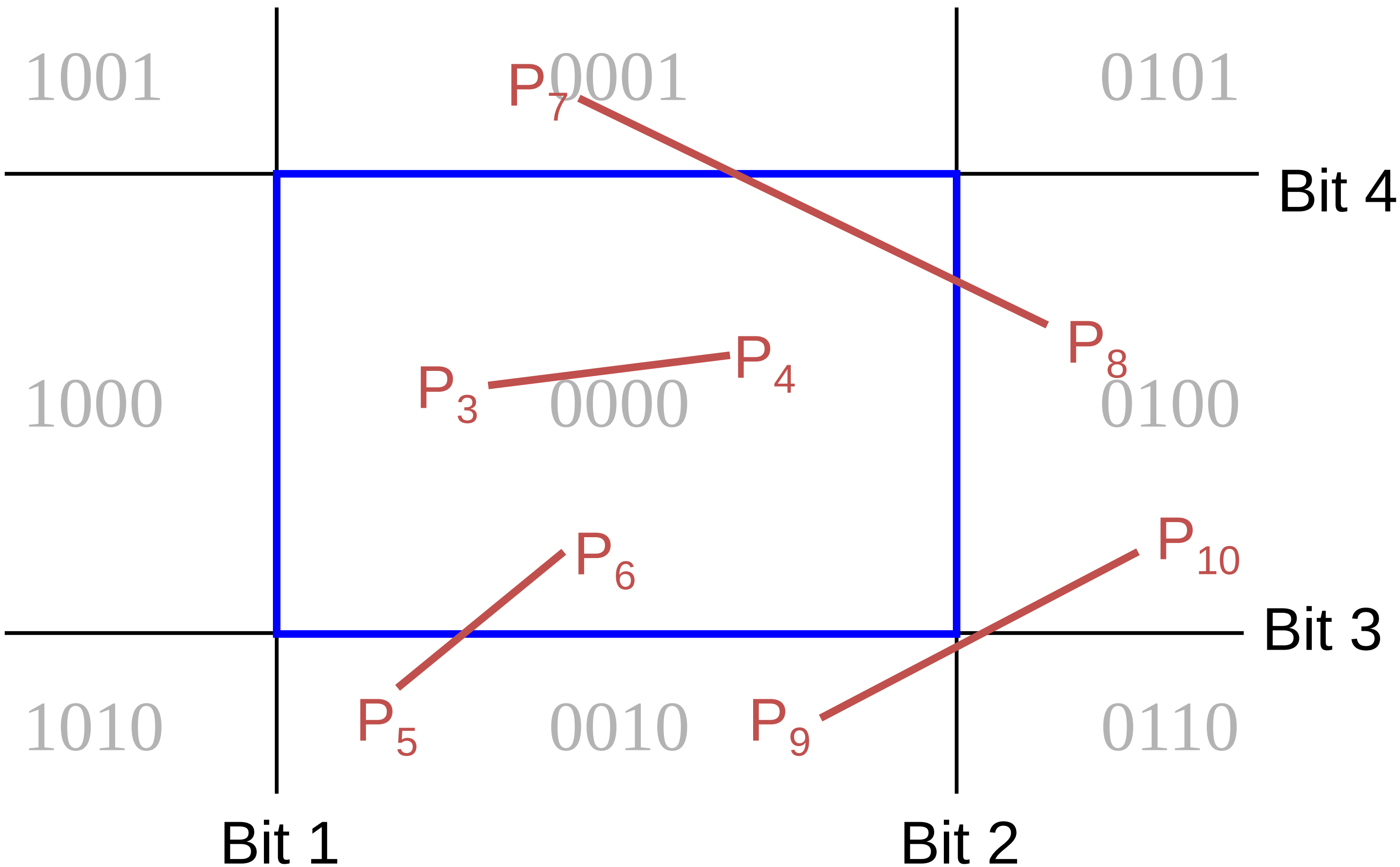

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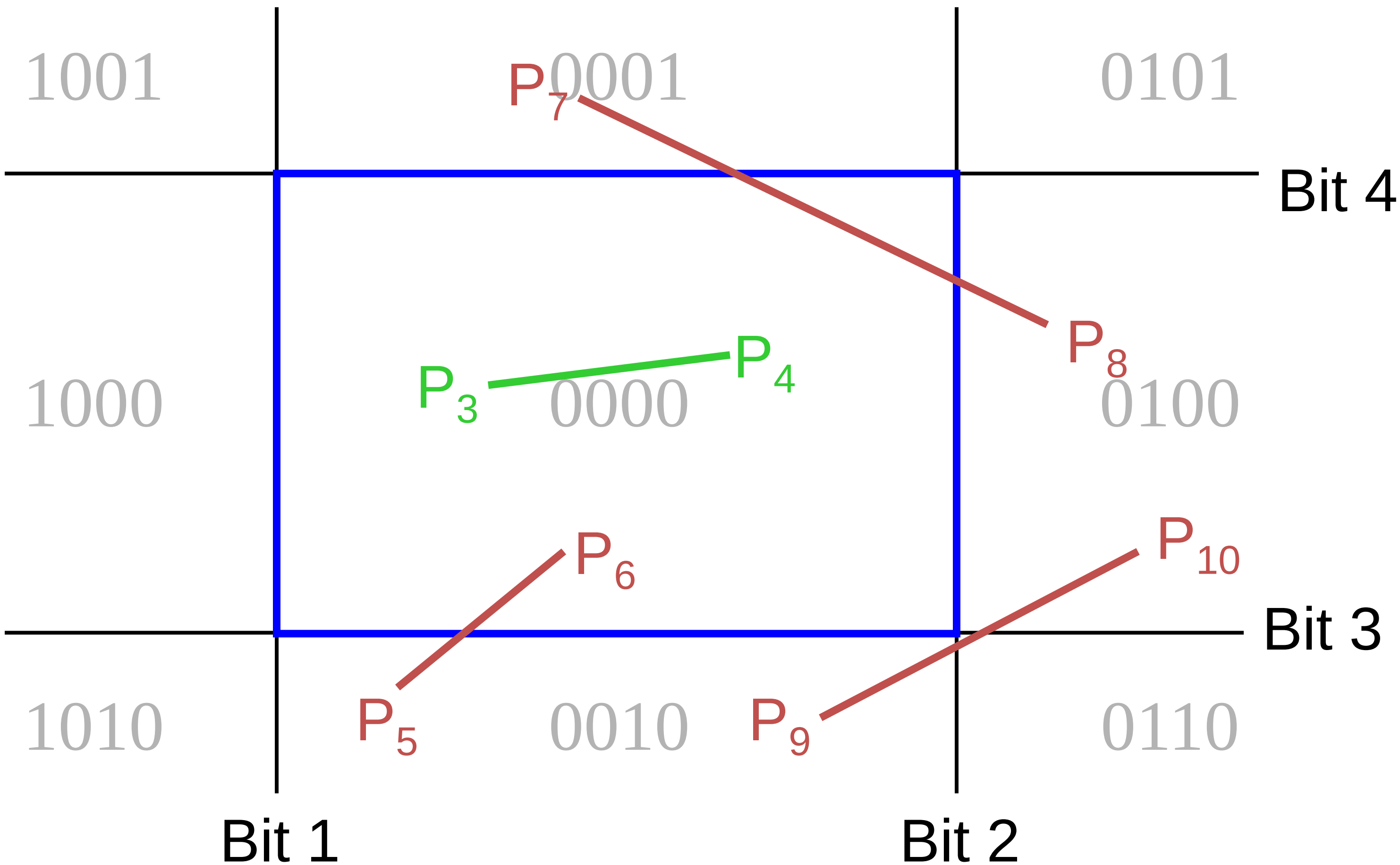
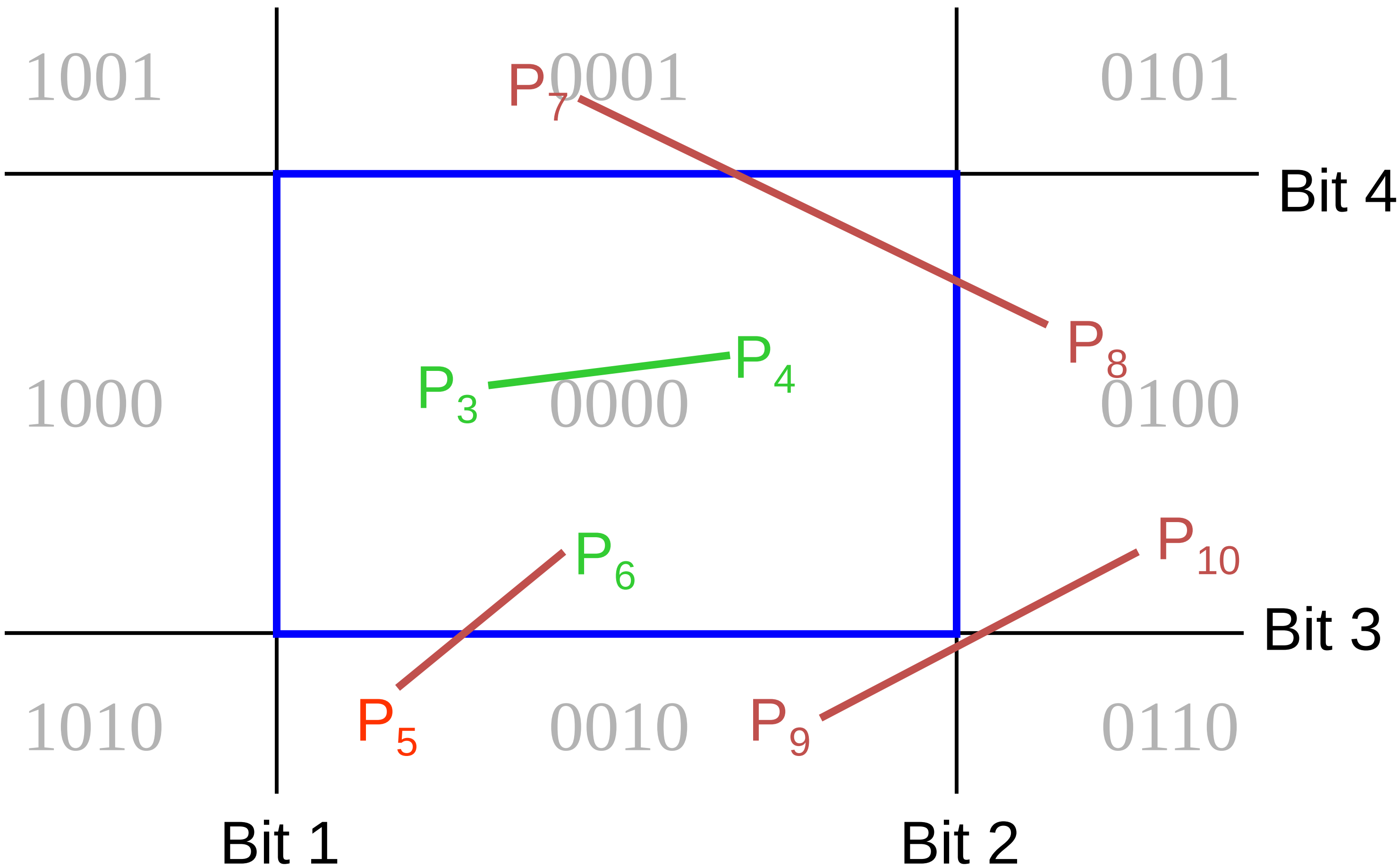


Cohen Sutherland Line Clipping

- Compute intersections with window boundary for lines that can't be classified quickly



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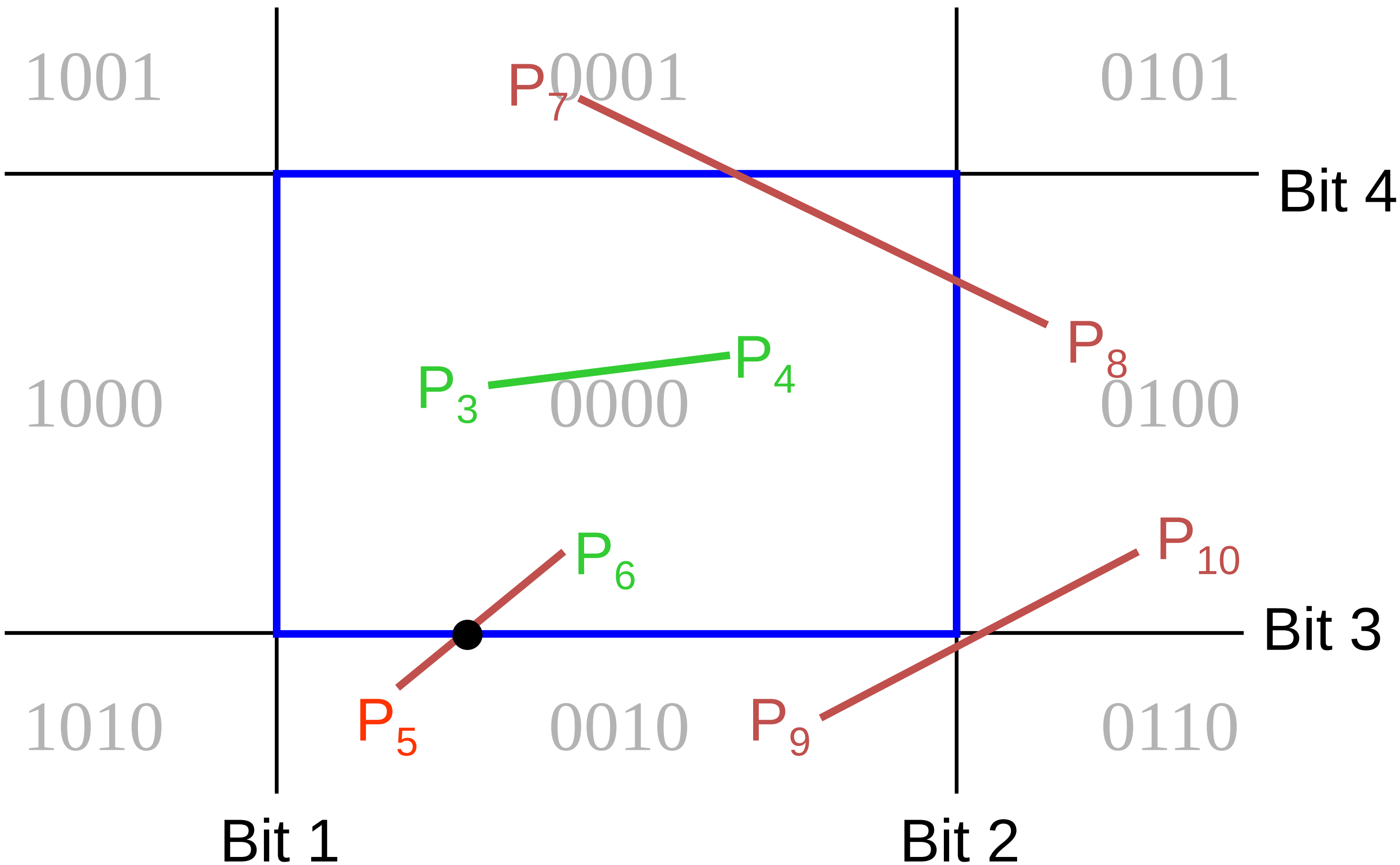

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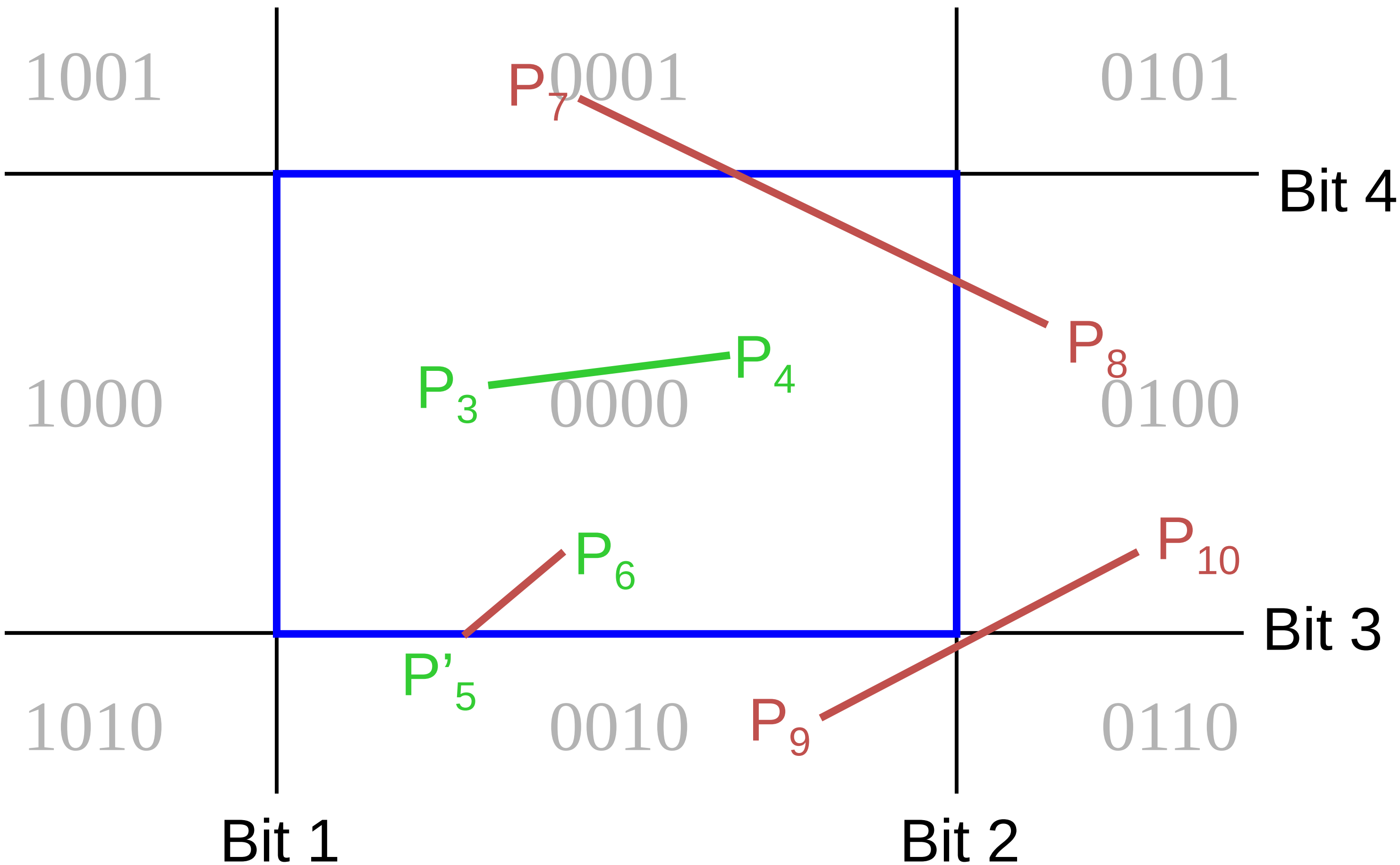

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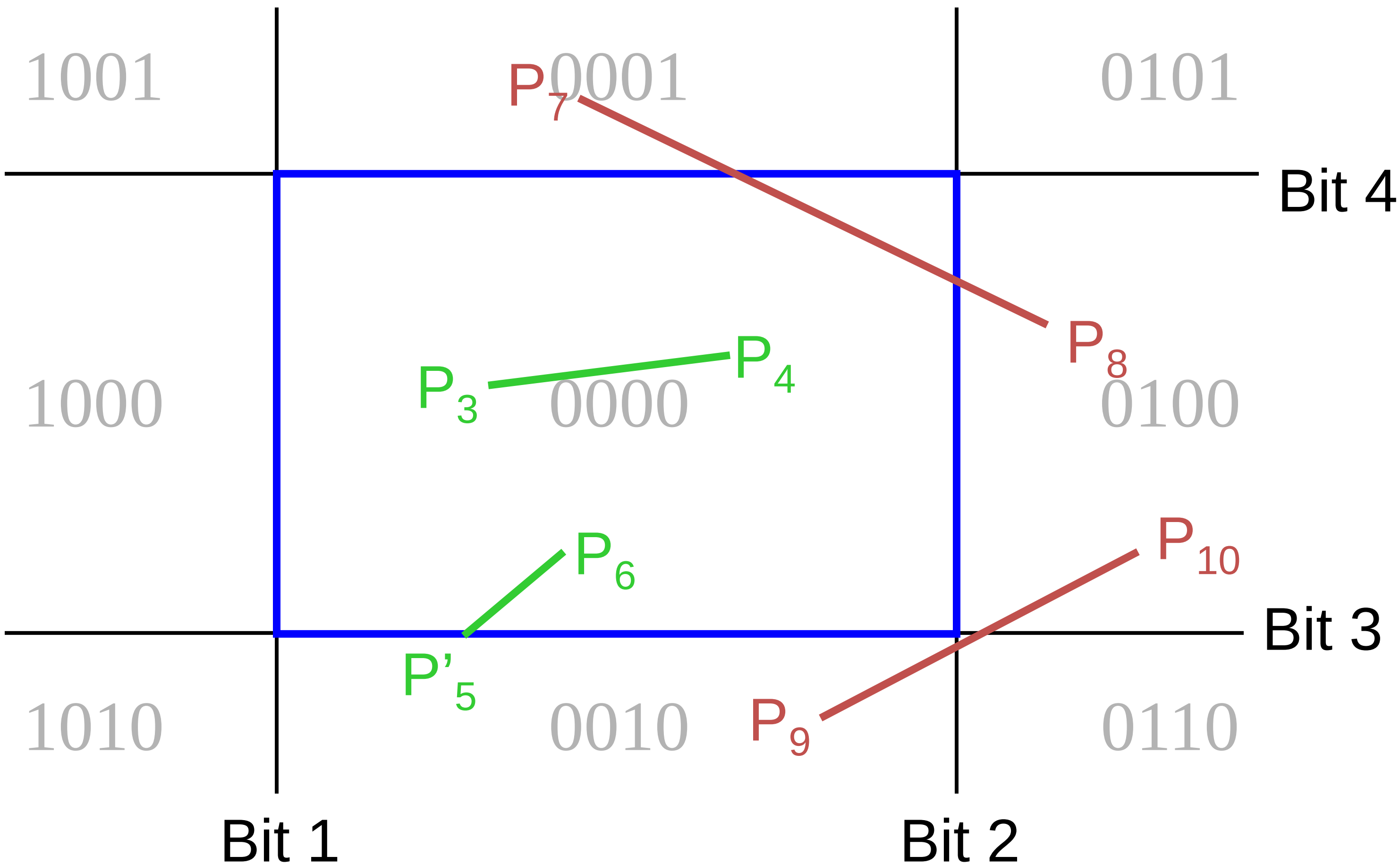

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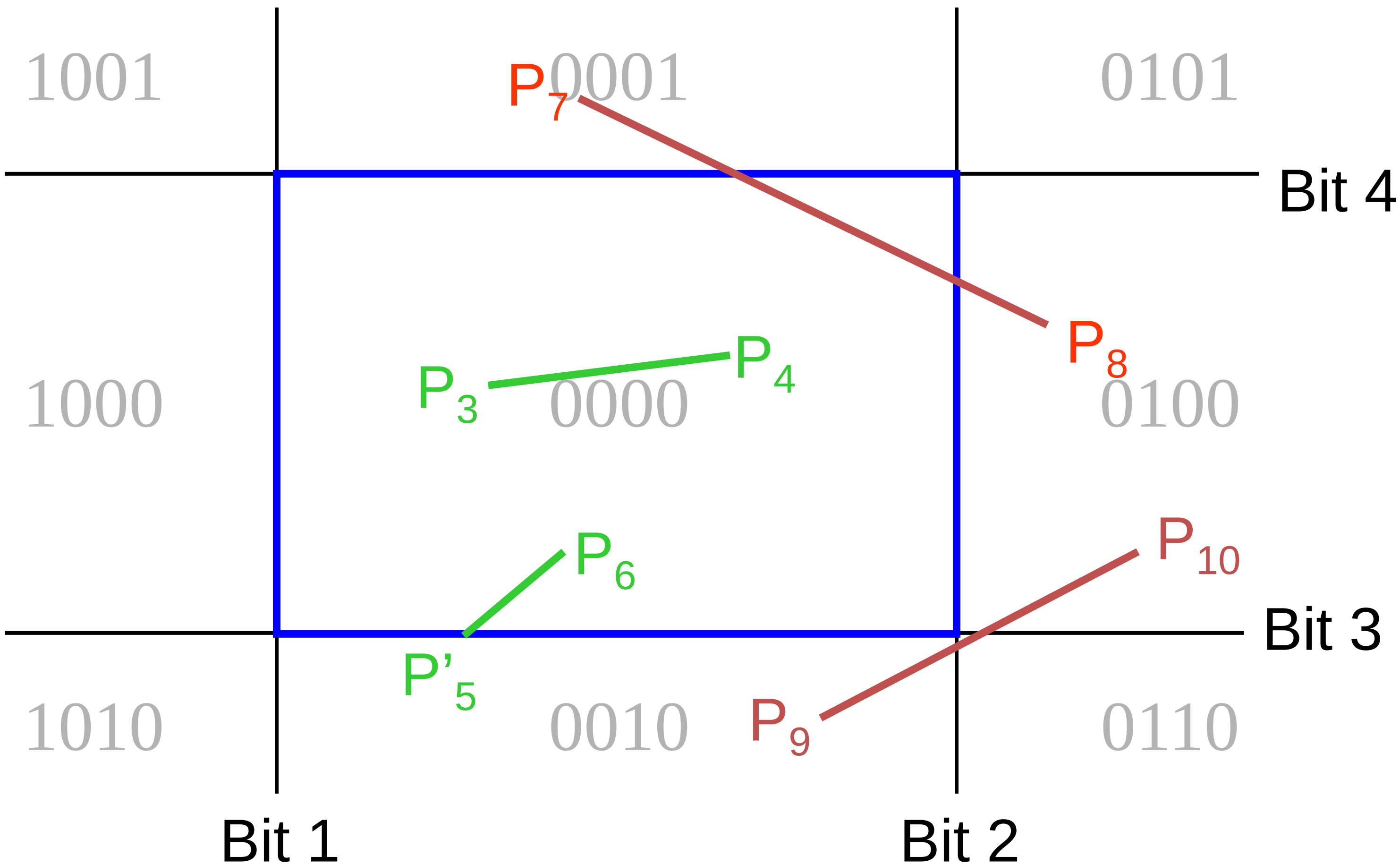

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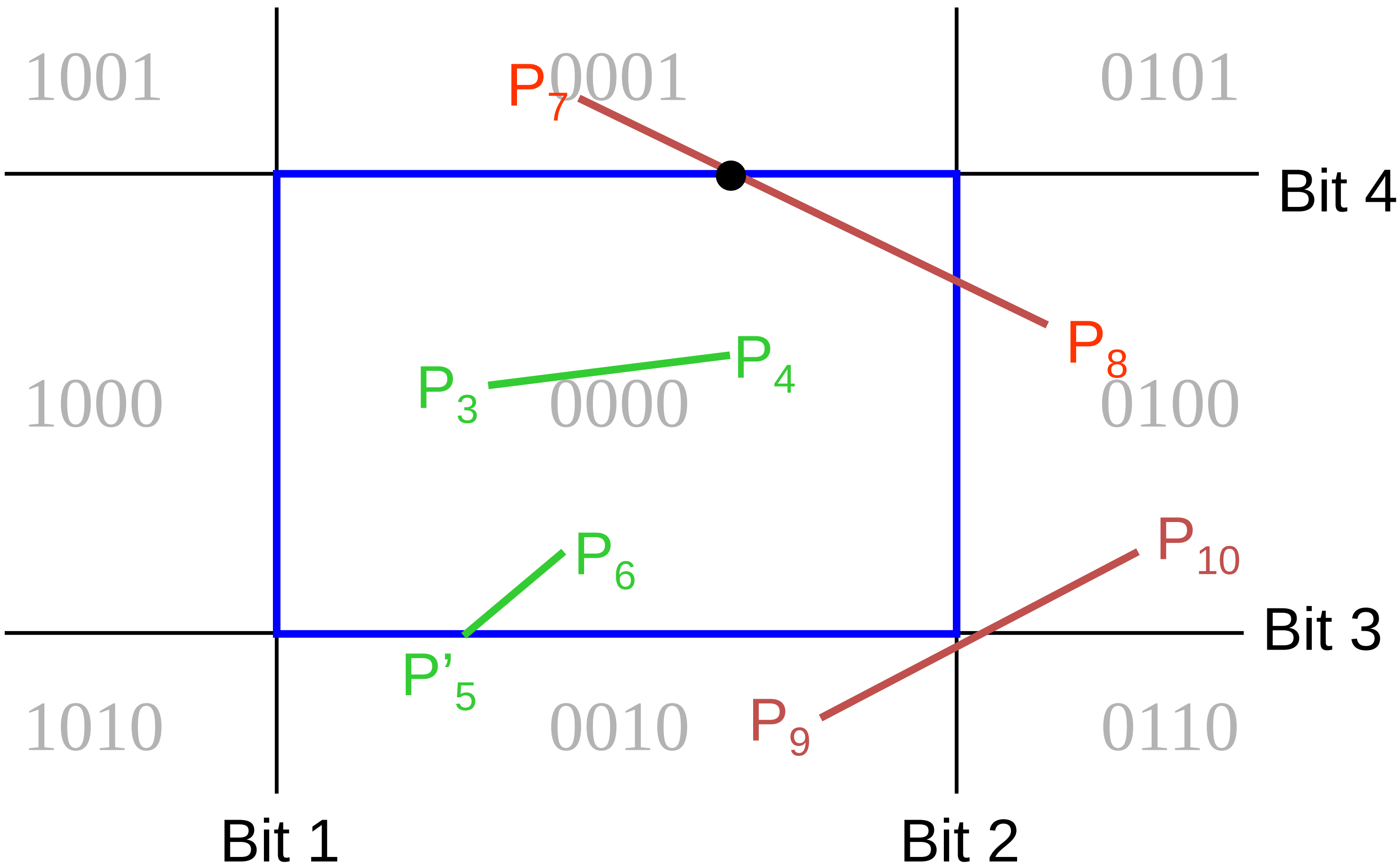

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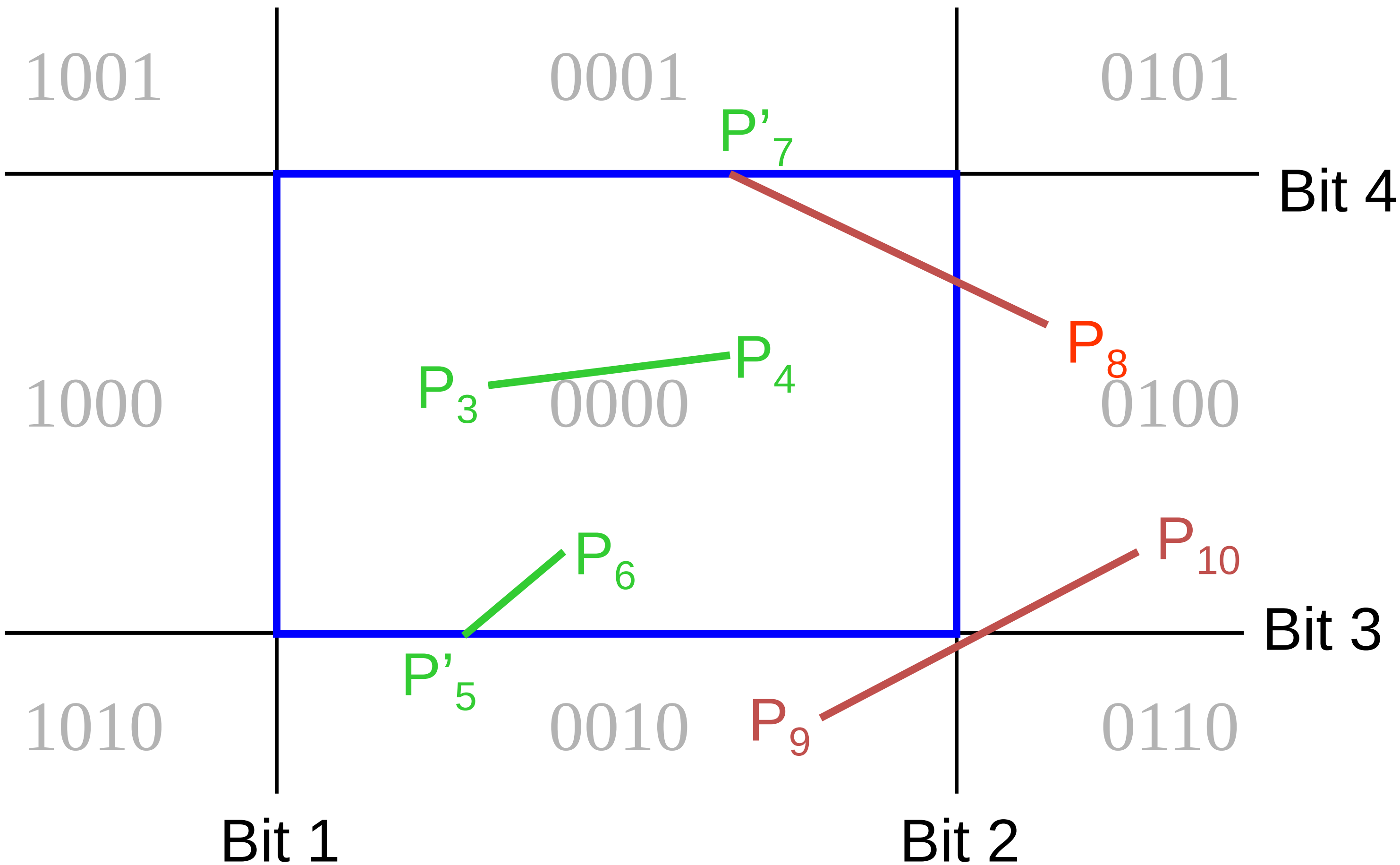

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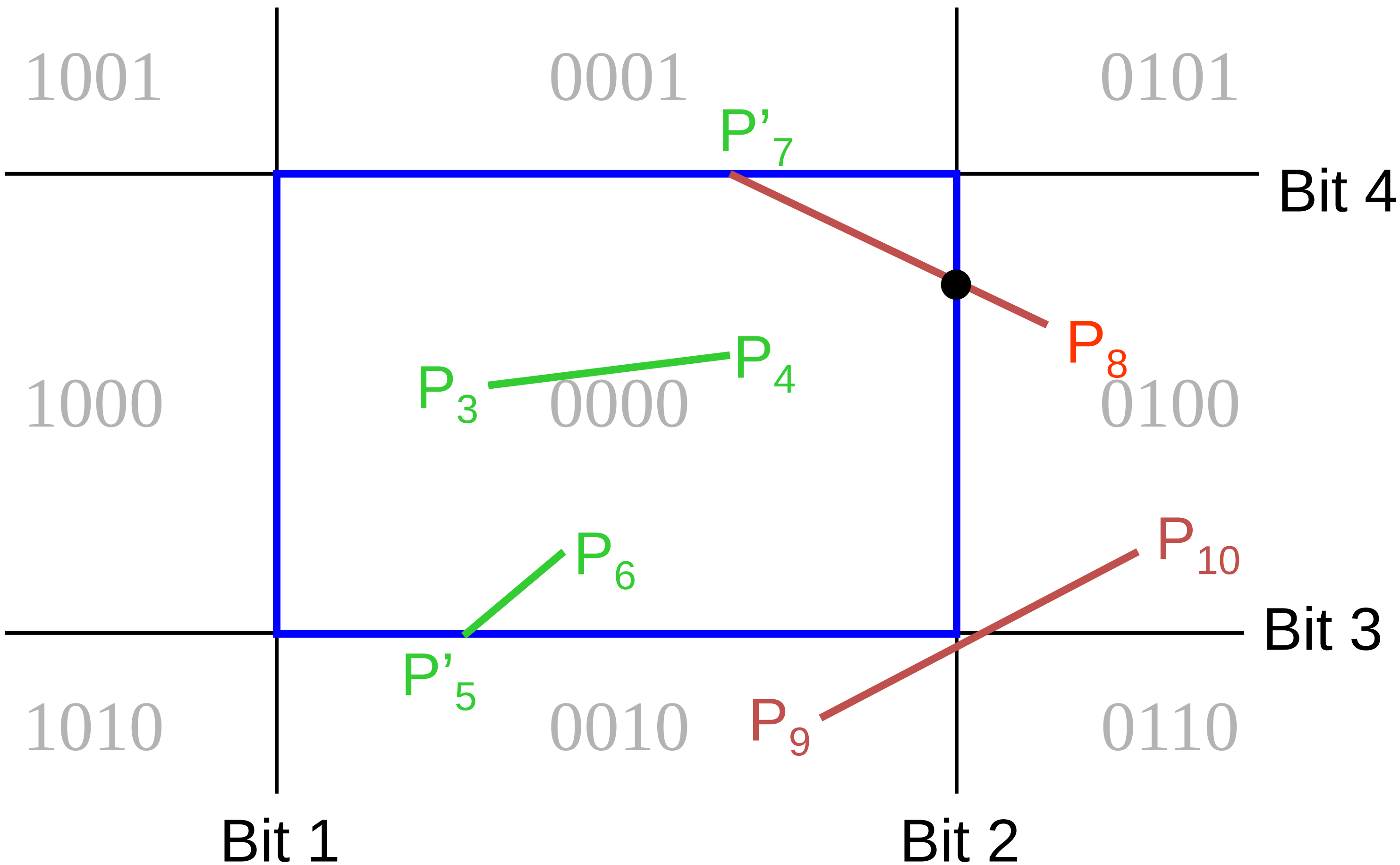

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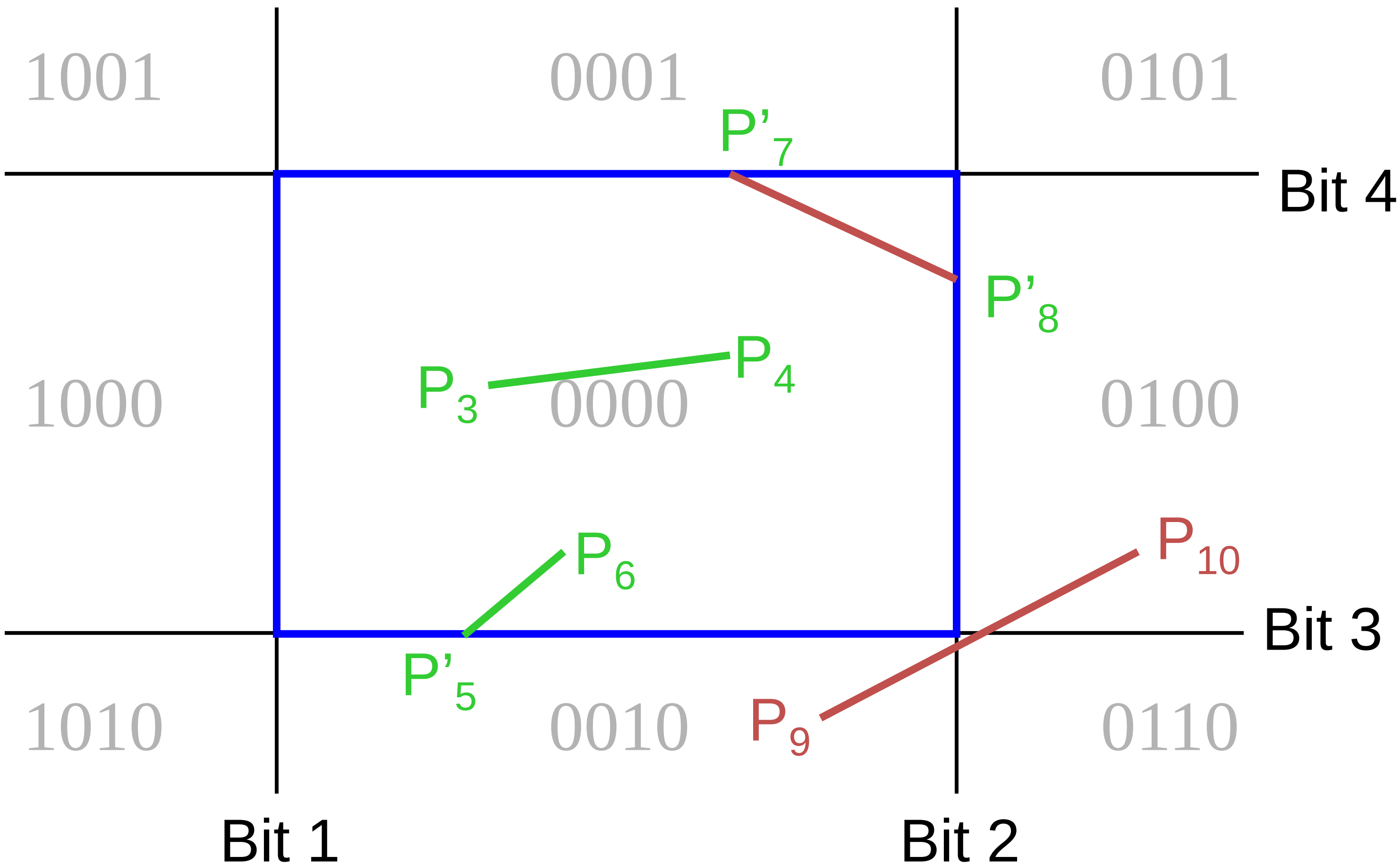

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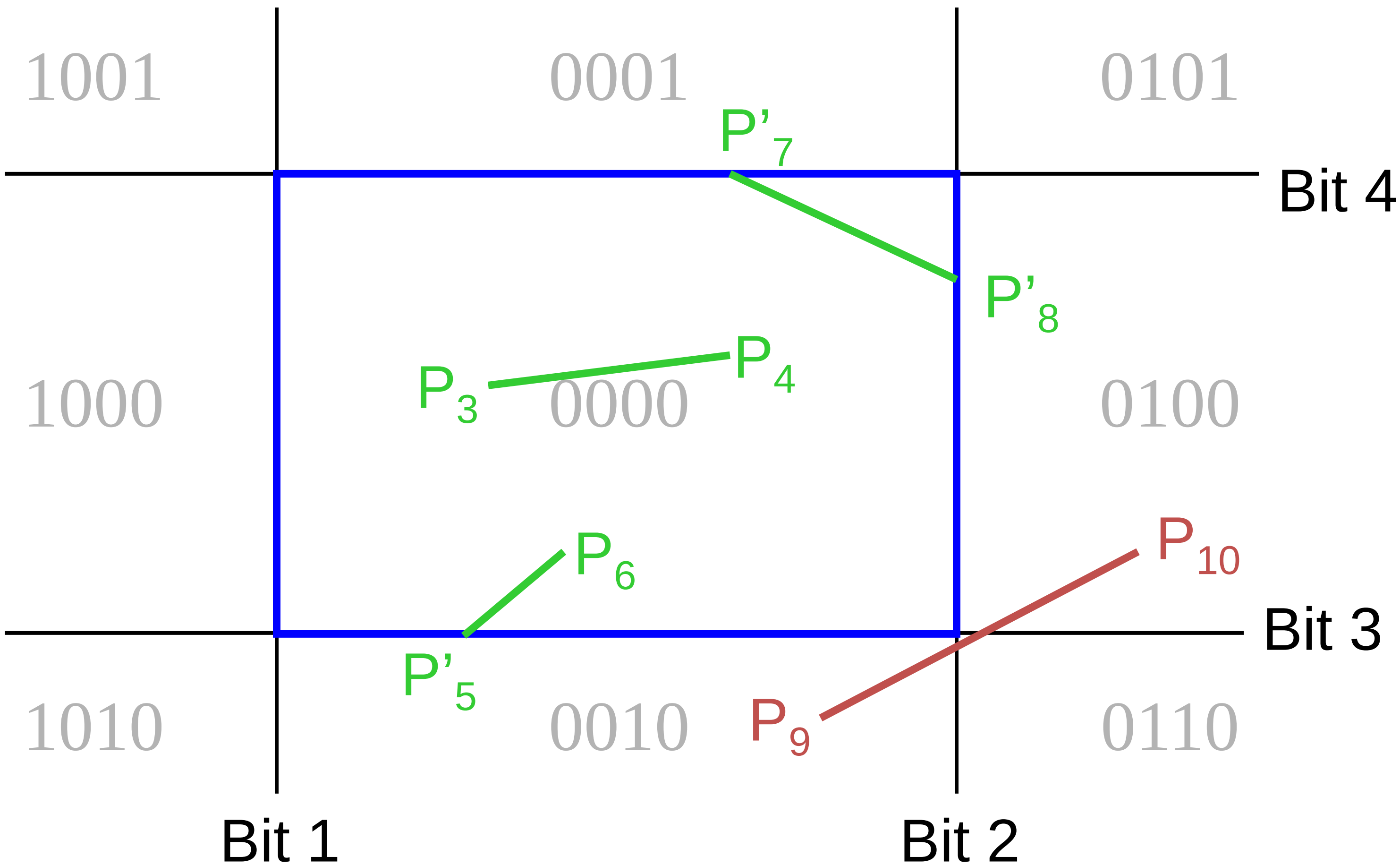

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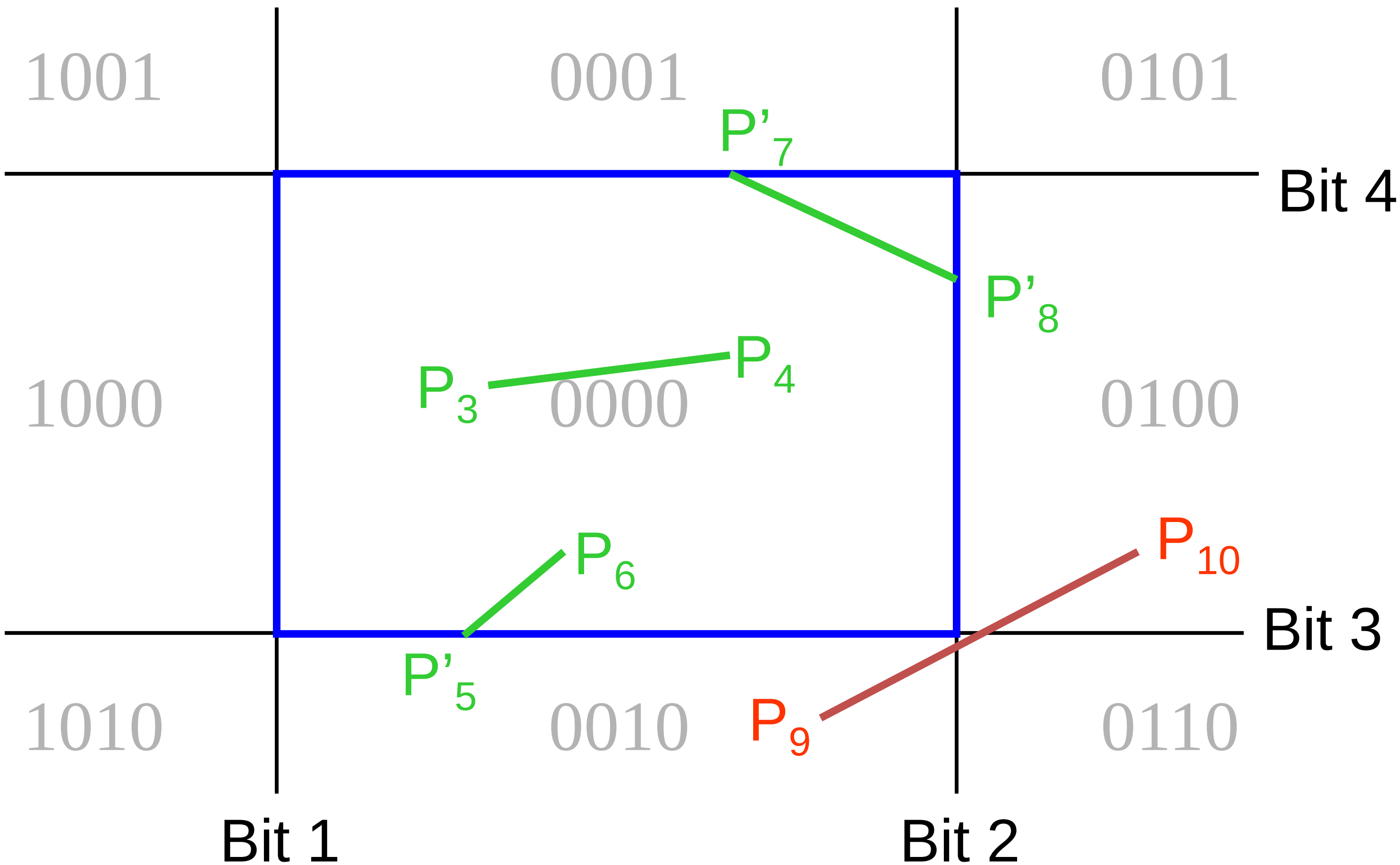

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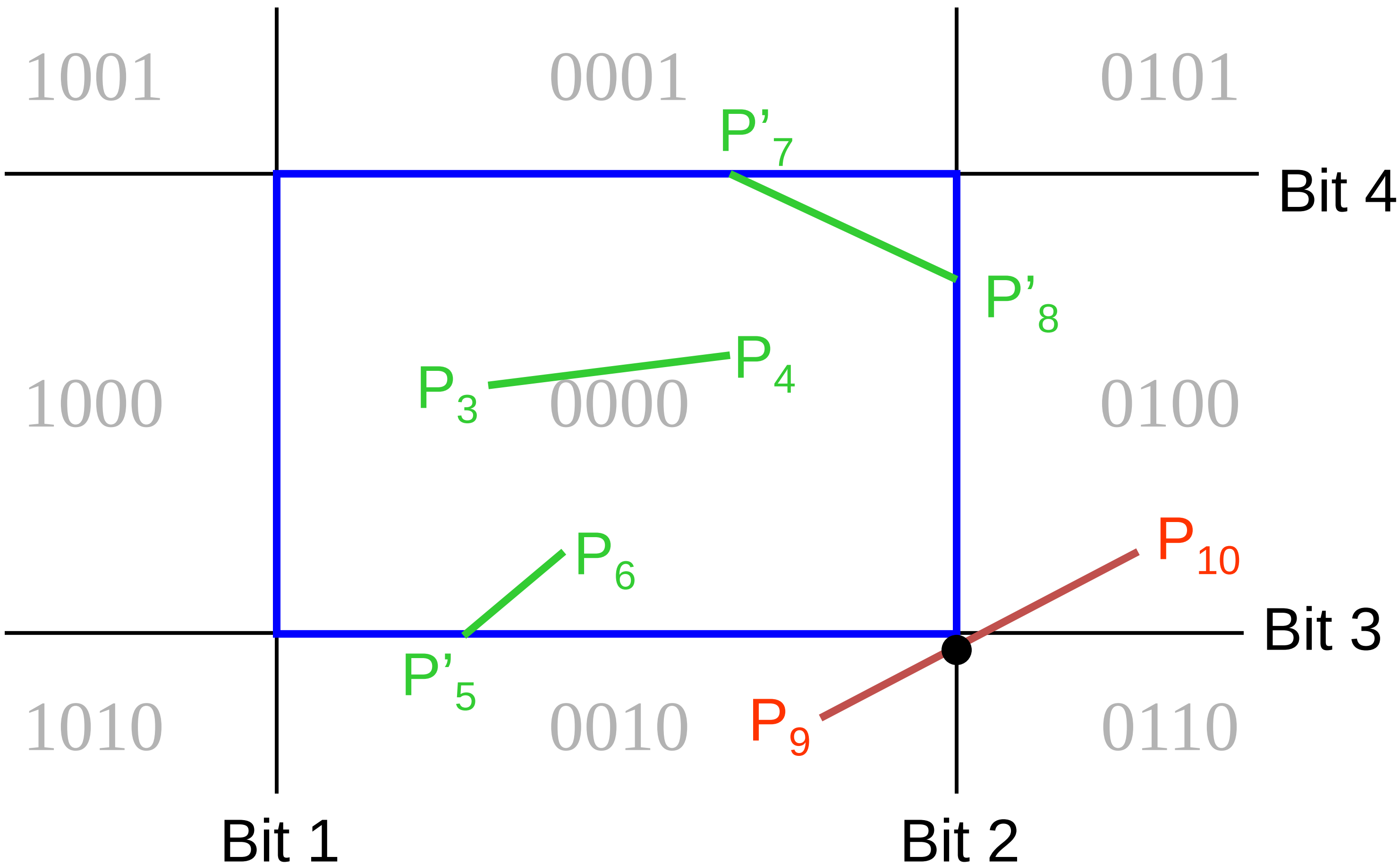

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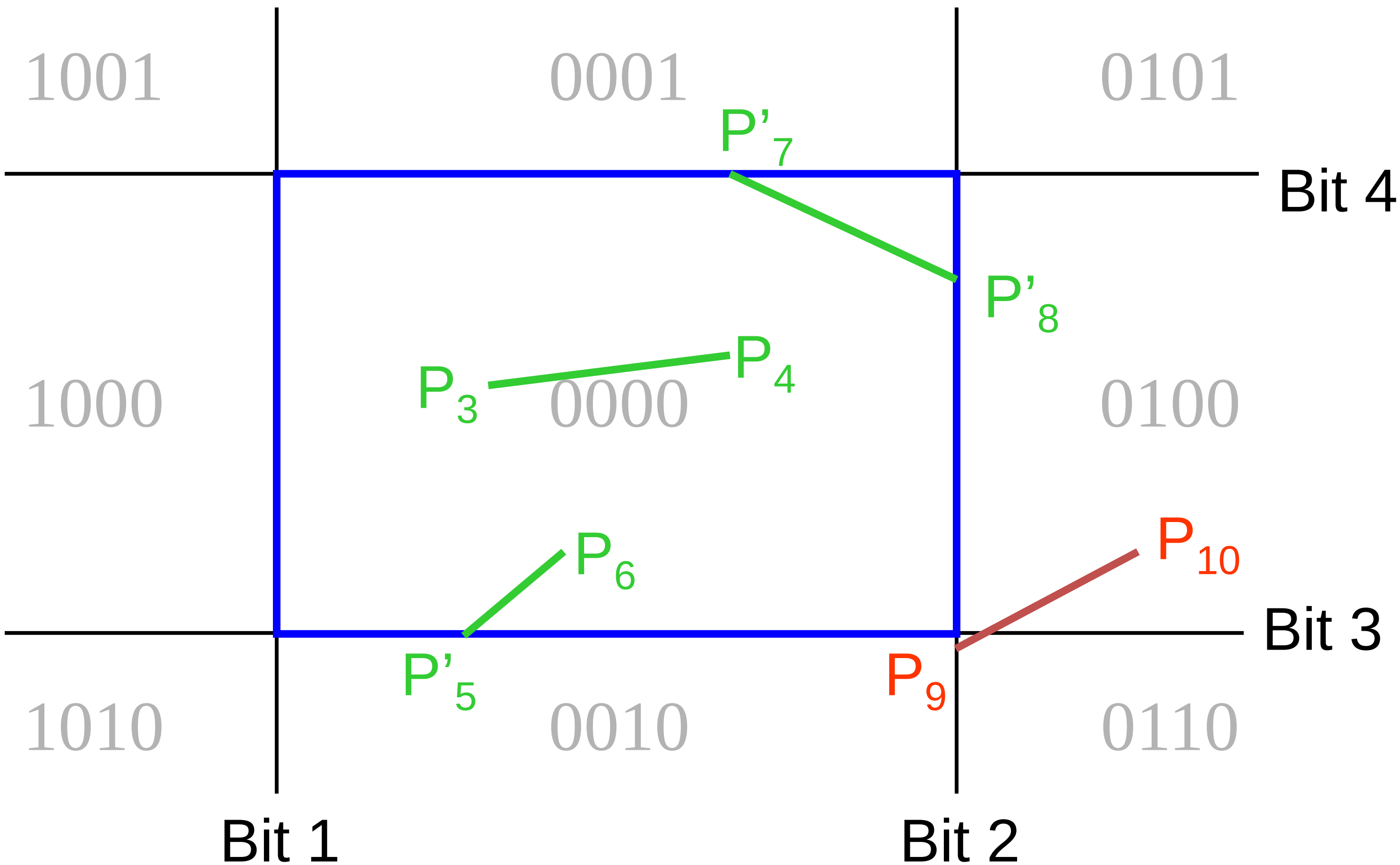

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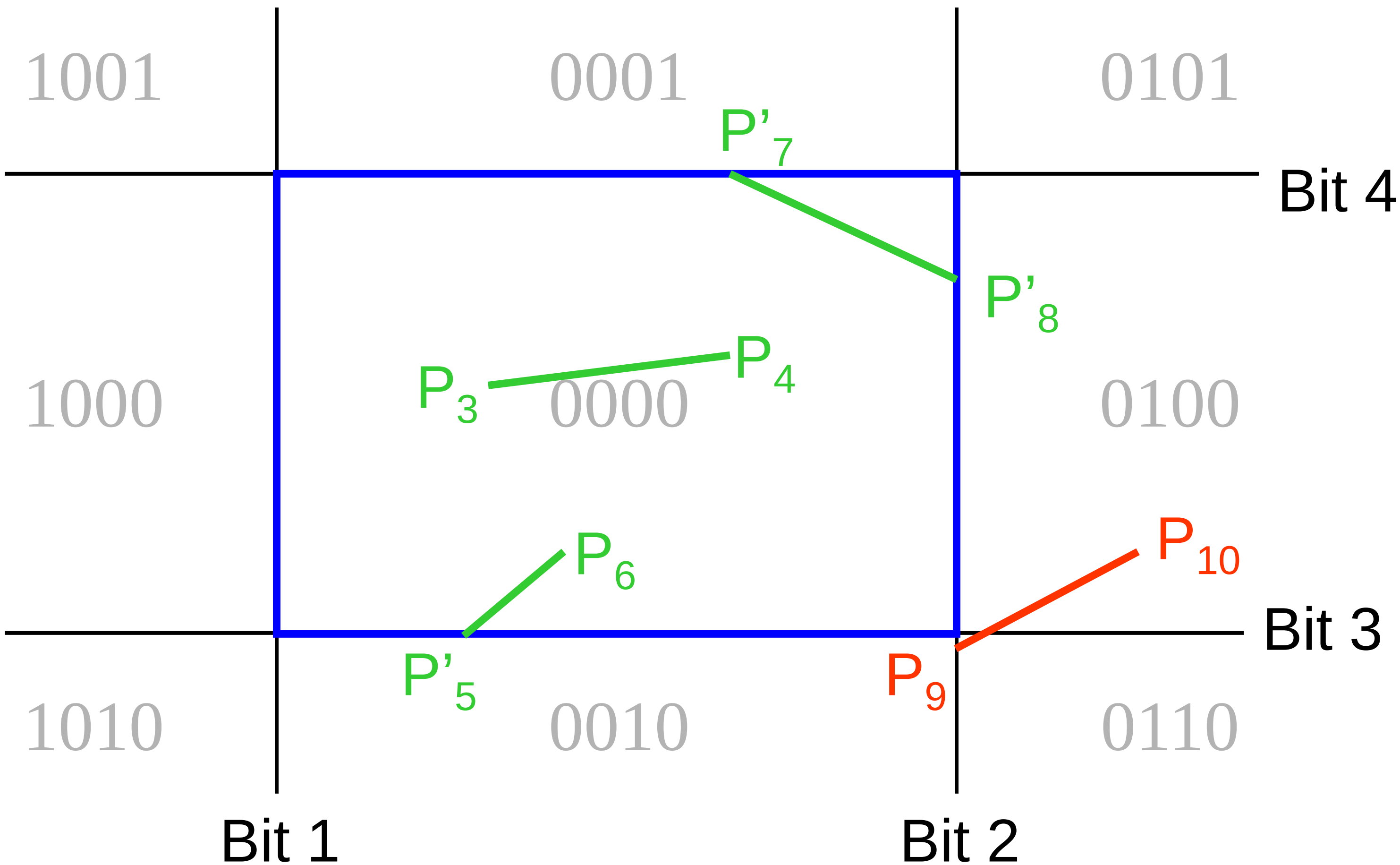

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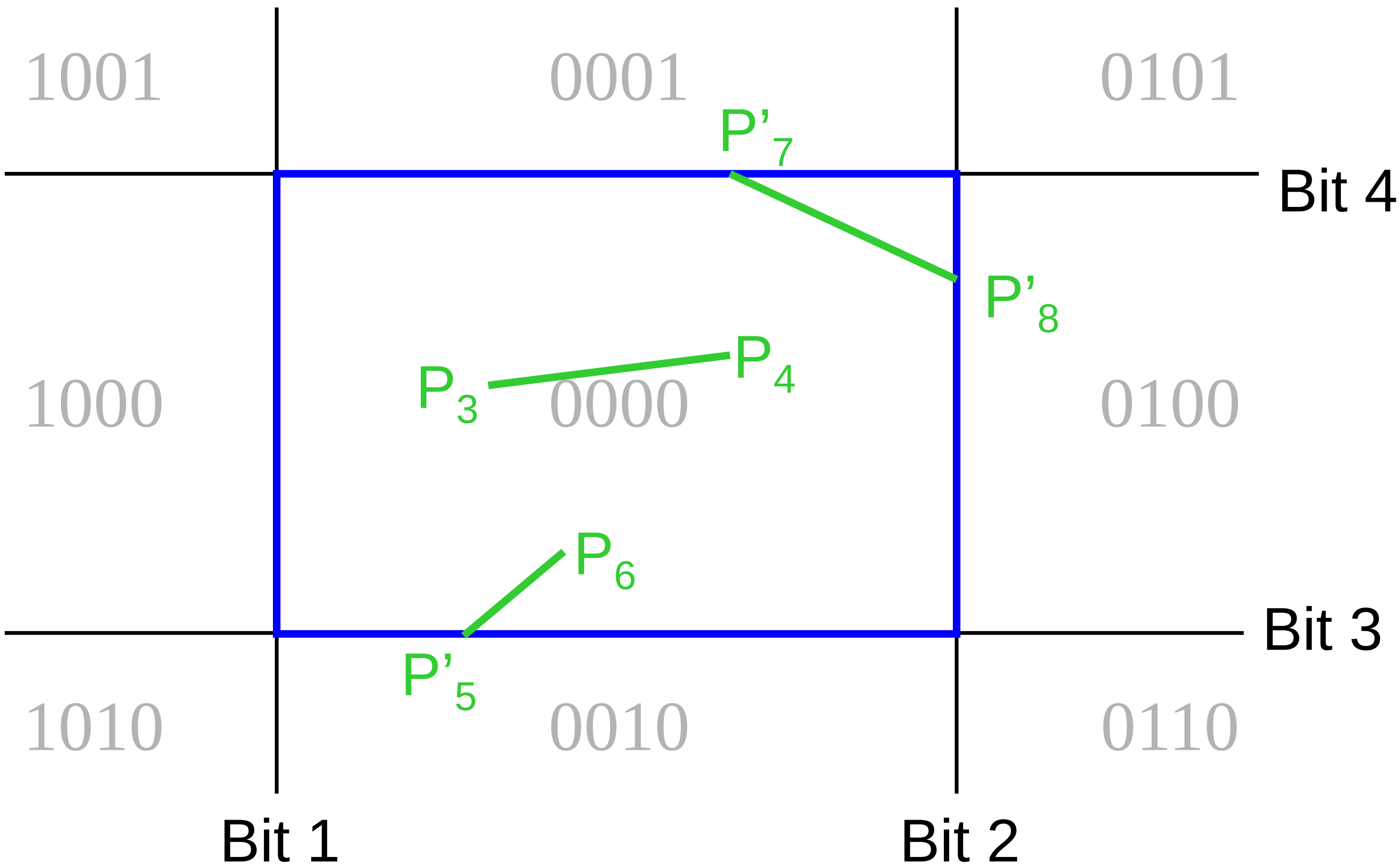


Cohen-Sutherland Algorithm

```
CompOutCode (x, y : real; var code : outcode);
/* Compute outcode for the point (x,y)  */
begin
    code := 0;
    if Y > Ymax then code := code | B1000
       else
           if Y < Ymin then code := code | B0100;
    if X > Xmax then code := code | B0010
       else
           if X < Xmin then code := code | B0001;
end;
```

Cohen-Sutherland Algorithm (cont.)

```
CS (x0,y0,x1,y1,xmin,xmax,ymin,ymax)
{
    boolean accept, done :;
    float outcode0, outcode1, x, y;
    accept := false ;
    done   := false ;
    CompOutCod (x0,y0,outcode0);
    CompOutCod (x1,y1,outcode1);
      repeat
            if  ((outcode0 | outcode1 ) == 0)
            {
             /*  Trivial accept  */
                   accept := true ;
                   done   := true ;
              }
            else
      if ((outcode0 & outcode1 ) <> 0){
             /*  Trivial reject  */
                    done := true
           }
            else
/* Failed both tests, so calculate the line segment to clip from an outside
point to an intersection with clip edge   */
```

Cohen-Sutherland Algorithm (cont.)

```
/* At least one endpoint is outside the clip rectangle, pick it*/
if (outcode0 <> 0) {
    outcodeOut := outcode0
else
    outcodeOut := outcode1;

/* now find the intrsection point by using the formulas:
y= y0 + slope*(x-x0), and
x = x0 + (1/slope)*(y-y0) */

if (outcodeOut & 0x1000) then
     divide line at top of clip rectangle;

else if (outcodeOut & 0x0100) then
     divide line at bottom of clip rectangle;

else if (outcodeOut & 0x0010) then
     divide line at right edge of clip rectangle;

else if (outcodeOut & 0x0001) then
     divide line at left edge of clip rectangle;
```

Cohen-Sutherland Algorithm (cont.)

```
/*  Now we move outside point to intersection point to
clip,
and get ready for next pass  */
if (outcodeOut == outcode0)
{
   x0:=x;y0:=y;CompOutCod (x0,y0,outcode0);
}
 else {
  x1:=x;y1:=y;CompOutCod (x1,y1,outcode1);
}

}  /* Subdivide  */
   until (done) ;

 if (accept) draw_line (x0,y0,y0,y1);
} /* end */
```

Vector Calculus - Preliminaries

A 2D vector V is defined as: $V=(V_x,V_y)$.

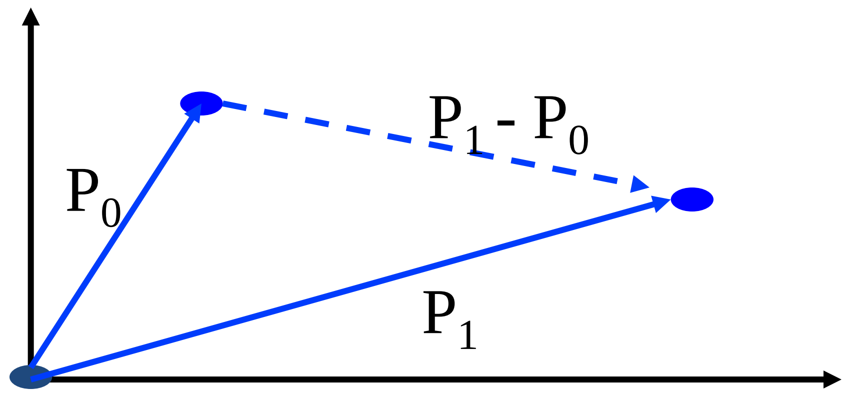
Scalar (dot) product between two vectors V and U is defined:

$$\mathbf{V}\cdot\mathbf{U}=\begin{bmatrix}\mathbf{V}_x & \mathbf{V}_y\end{bmatrix}\begin{bmatrix}\mathbf{U}_x\\ \mathbf{U}_y\end{bmatrix}=$$

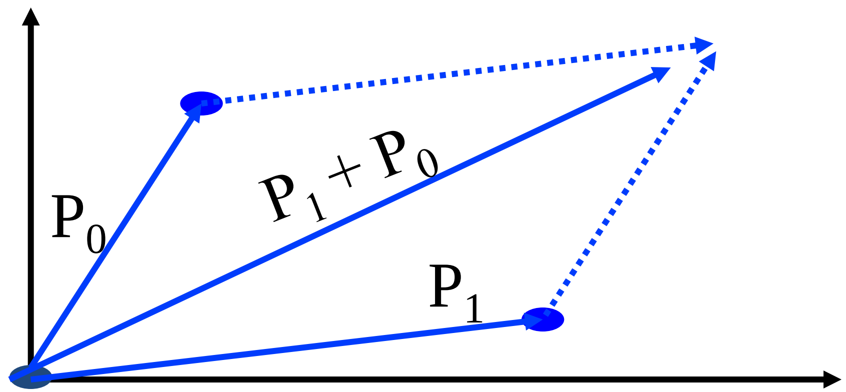
$$\mathbf{V}_x\mathbf{U}_x+\mathbf{V}_y\mathbf{U}_y=|\mathbf{V}||U|\cos\theta$$

If $V\cdot U=0$ then V and U are perpendicular to each other.

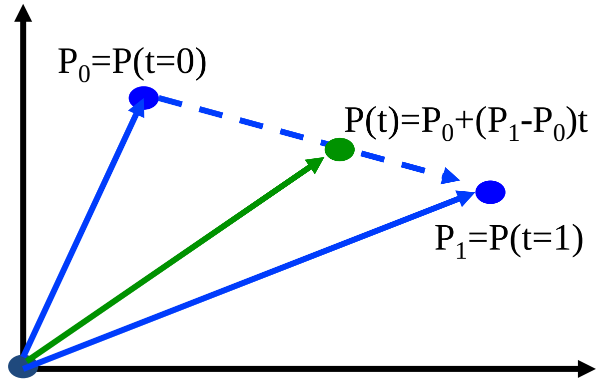
Vector Subtraction



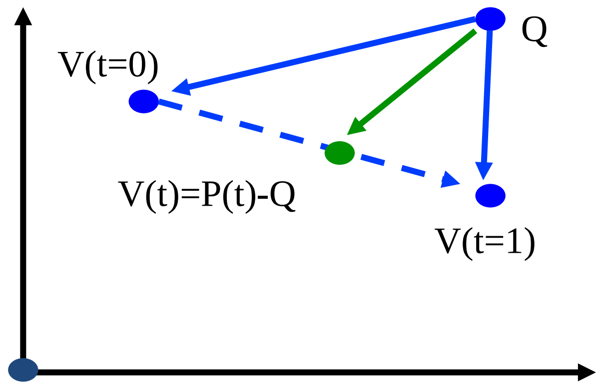
Vector Addition



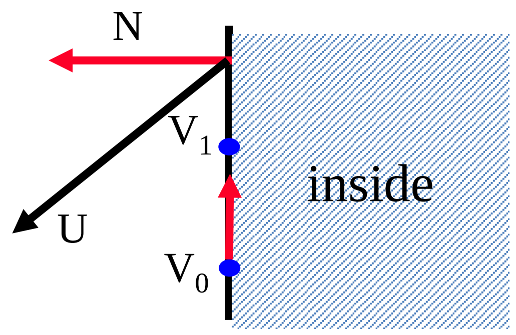
Parametric Line



Changing the Origin



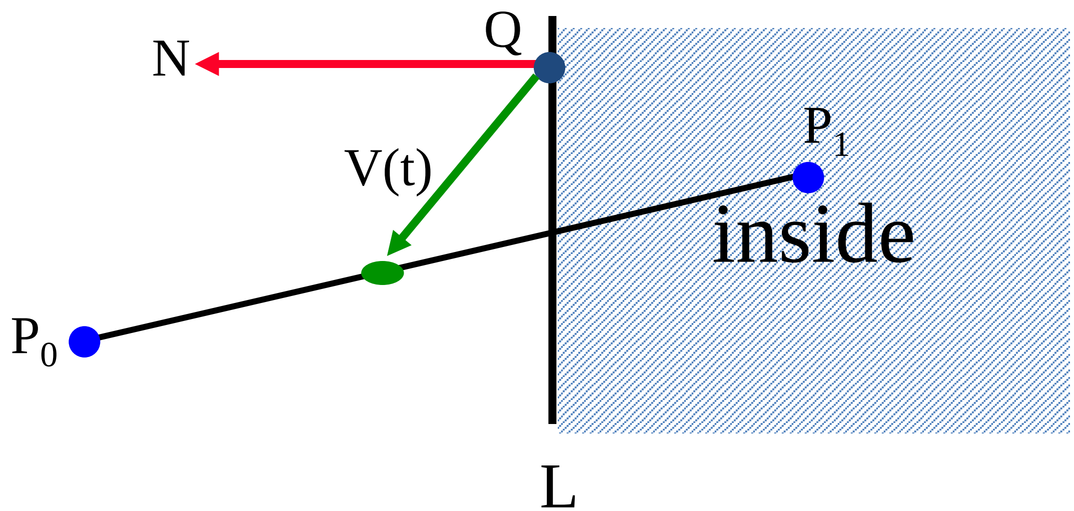
Inside/Outside Test



- Assume WLOG that $V=(V_1-V_0)$ is the border vector where "inside" is to its right.
- If $V=(V_x,V_y)$, N is a prep' vector pointing outside, where we define:

  $N=(-V_y,V_x)$
- Vector U points "outside" if $N \cdot U > 0$
- Otherwise U points "inside".

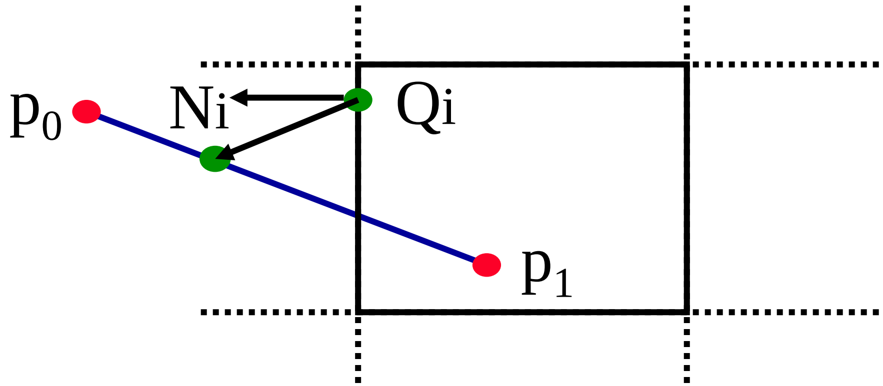
Segment-Line Intersection



- The parametric line $P(t)=P_0+(P_1-P_0)t$
- The parametric line $V(t)=P(t)-Q$
- The segment intersects the line L at t_0 satisfying $V(t_0) \cdot N=0$.
- The intersection point is $P(t_0)$.
- The vector $\Delta=P_1-P_0$ points "inside" if $(P_1-P_0) \cdot N<0$.

  Otherwise it points "outside".
- If L is vertical, intersection can be computed using the explicit equation.

Cyrus-Beck Line Clipping



- Denote $p(t)=p_0+(p_1-p_0)t \quad t\in[0..1]$
- Let Q_i be a point on the edge L_i with outside pointing normal N_i.
- $V(t) = p(t)-Q_i$ is a parameterized vector from Q_i to the segment P(t).
- $Ni \cdot V(t) = 0$ iff $V(t) \perp N_i$
- We are looking for *t* satisfying the above equation:

Cyrus-Beck Clipping (cont.)

$$0 = Ni \cdot V(t) = Ni \cdot (p(t)-Q_i)$$

$$= Ni \cdot (p_0+(p_1-p_0)t-Q_i) = Ni \cdot (p_0-Q_i) + Ni \cdot (p_1-p_0)t$$

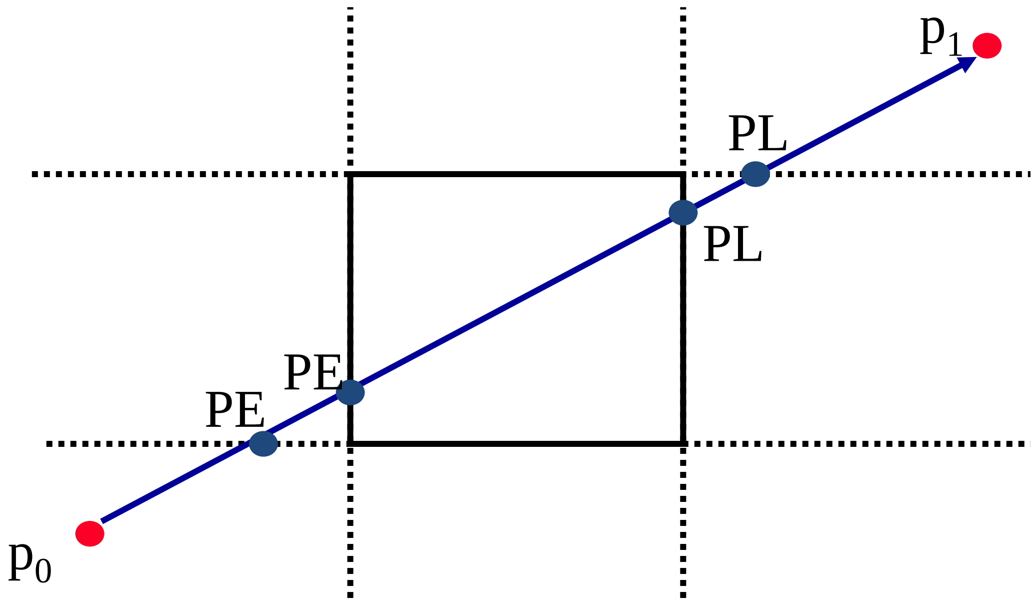
Solving for t we get:

$$t = \frac{Ni \cdot (p_0-Q_i)}{-Ni \cdot (p_1-p_0)} = \boxed{\frac{Ni \cdot (p_0-Q_i)}{-Ni \cdot \Delta}}$$

where $\Delta=(p_1-p_0)$

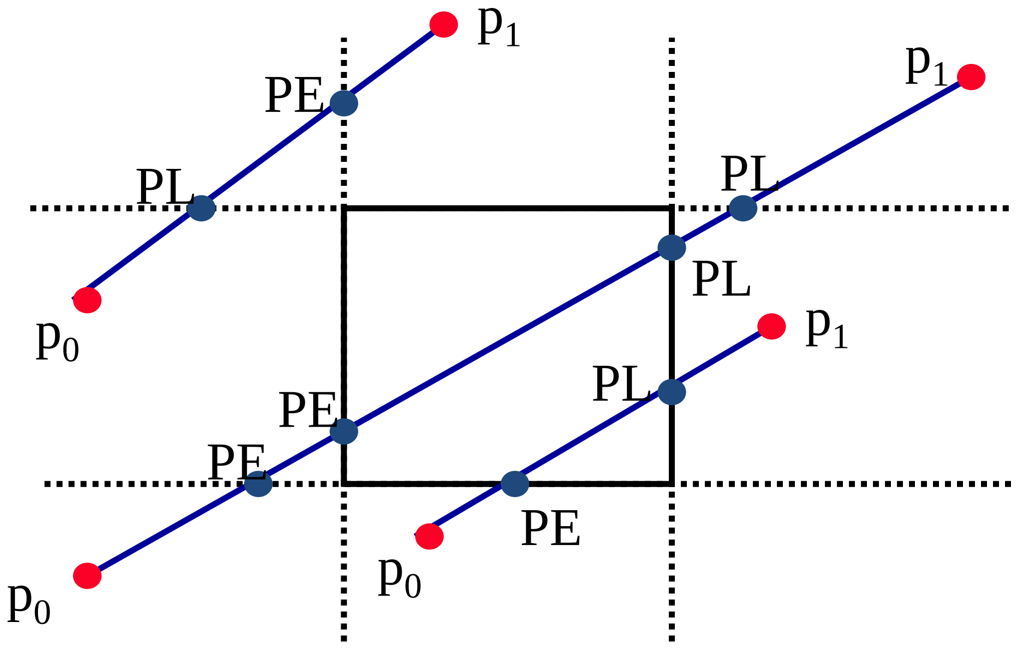
- **Comment**: If $Ni \cdot \Delta=0$, t has no solution.
  However, in this case $V(t) \perp N_i$ and there is no intersection.

potentially Entering and potentially Leaving



Cyrus-Beck Algorithm:

- The intersection of *p(t)* with all four edges L_i is computed, resulting in up to four t_i values.
- If $t_i<0$ *or* $t_i>1$, t_i can be discarded.
- Based on the sign of $Ni \cdot \Delta$, each intersection point is classified as ***PE*** (potentially entering) or ***PL*** (potentially leaving).
- ***PE*** with the largest *t* and ***PL*** with the smallest *t* provide the domain of p(t) inside *W*.
- The domain, if inverted, signals that p(t) is totally outside.

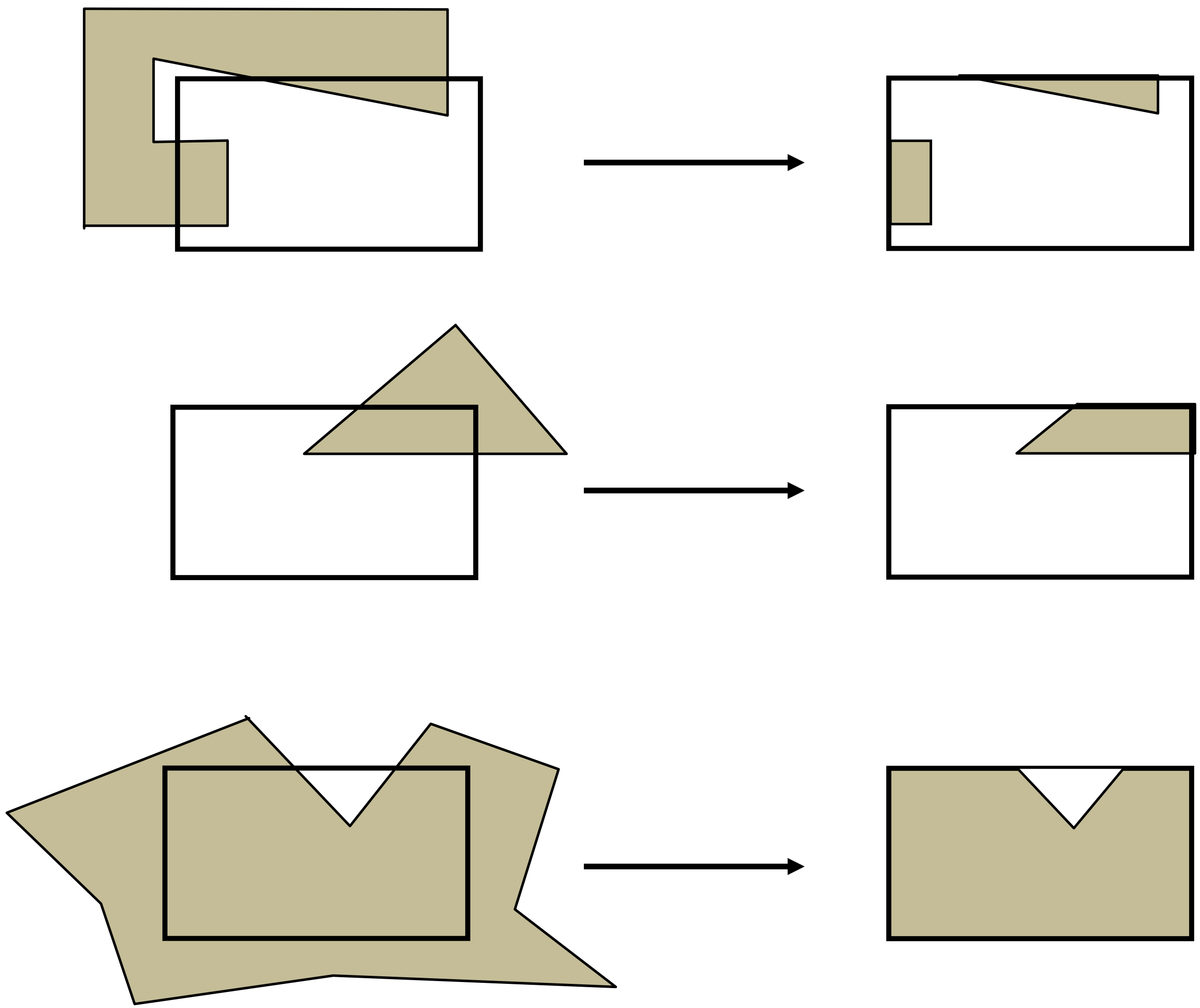


p_1
PE
p_1
PL
PL
PL
p_0
p_1
PL
PE
PE
PE
p_0
p_0

Cyrus-Beck Line Clipping

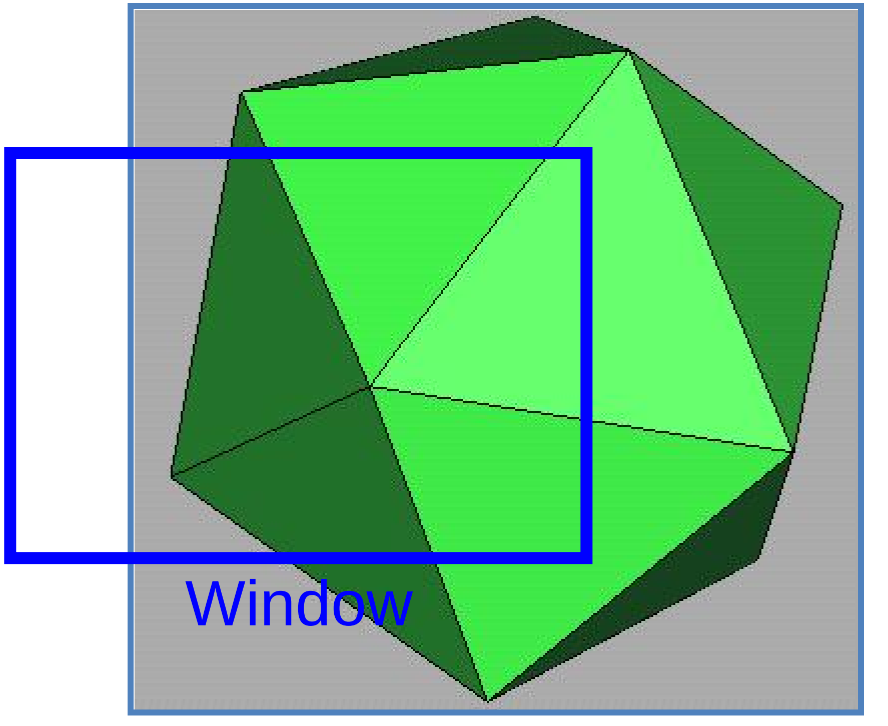
```
precalculate Ni and select a Pei for each edge;

for each line segment to be clipped
   if ( P1 = P2 ) then
                    line is degenerate so clip as a point;
  else {
          tPE = 0;  tPL = 1;
        for each candidate intersection with a clip edge
           if (( <Ni, D> ) <> 0 ) then {
              /* Ignore edges parallel to line for now */
                calculate t;
               sign of <Ni, D> categorizes as PE or PL ;
                              if  PE then tPE = max (tPE, t);
                              if  PL then tPL = min  (tPL, t);
                              }
                    if  (tPE > tPL) return null
                    else
                           return P(tPE) and P(tPL) ;
                    /* as true clip intersections */
              };
```

Polygon Clipping



Clipping

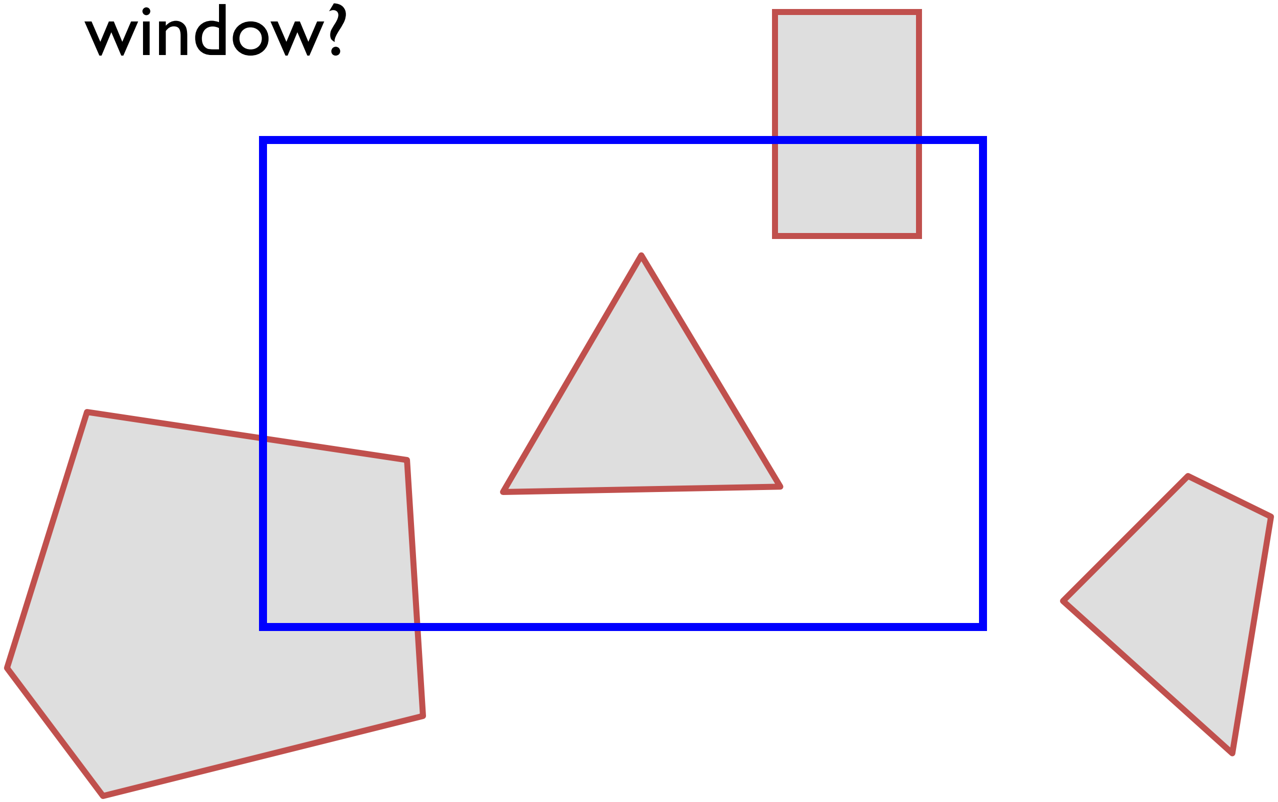
- Avoid drawing parts of primitives outside window
  - Points
  - Lines
  - Polygons
  - Circles
  - etc.



2D Screen Coordinates

Polygon Clipping

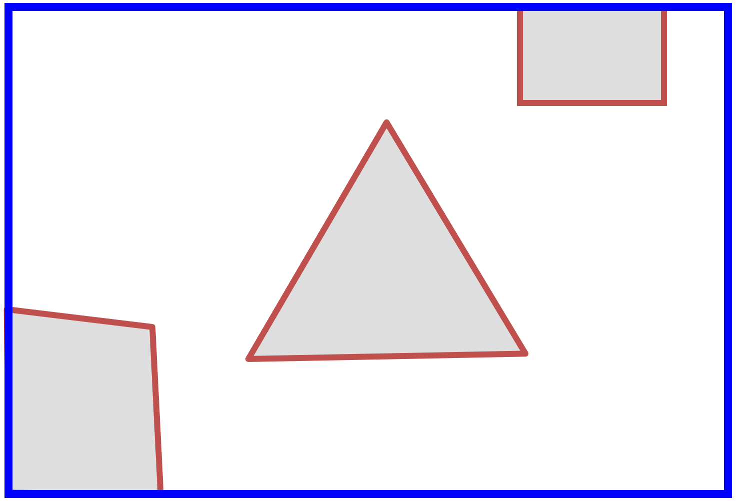
- Find the part of a polygon inside the clip window?



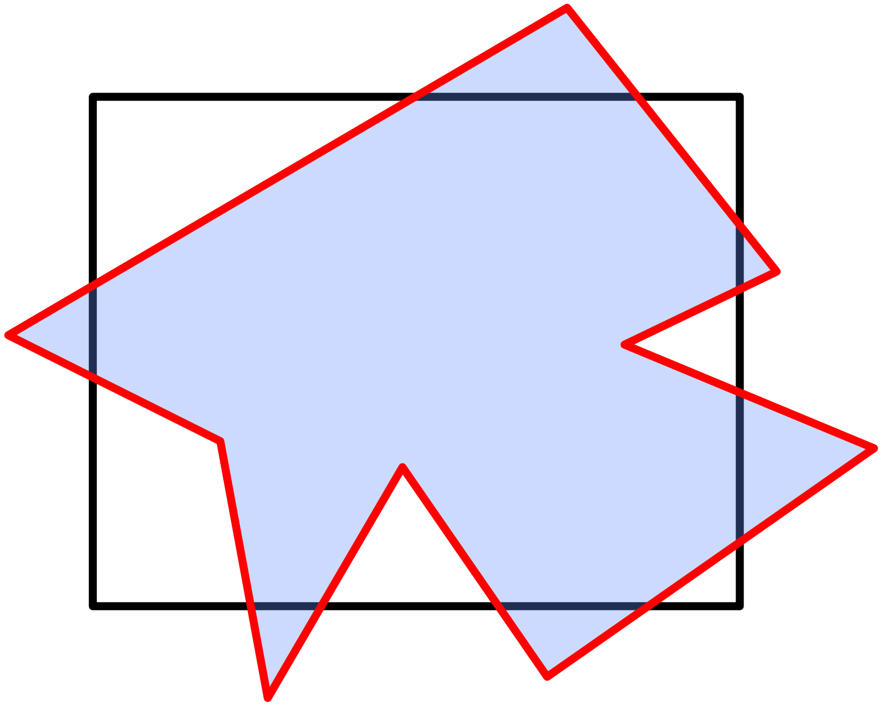
Before Clipping

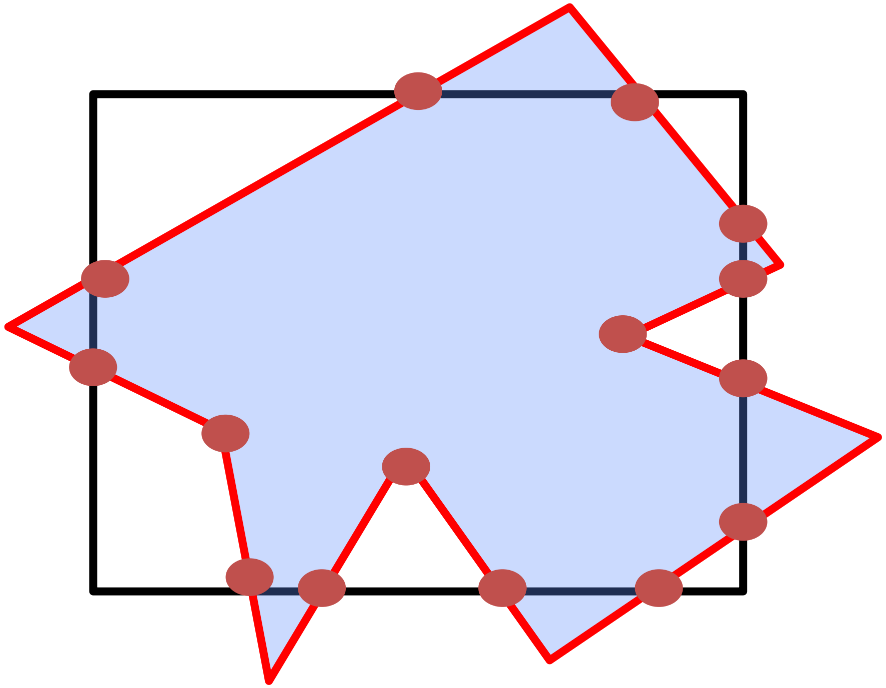
Polygon Clipping

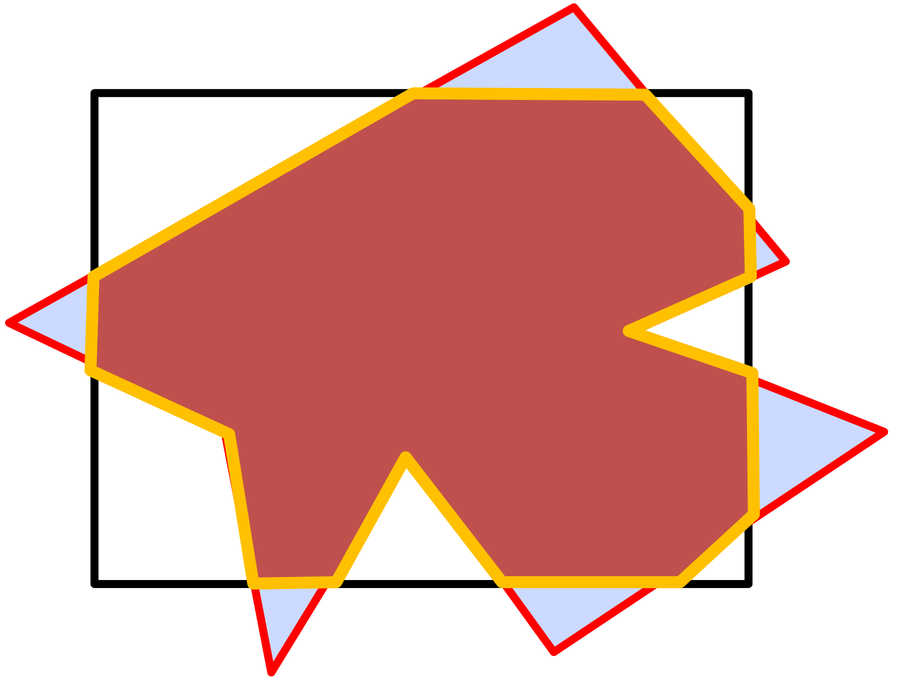
- Find the part of a polygon inside the clip window?

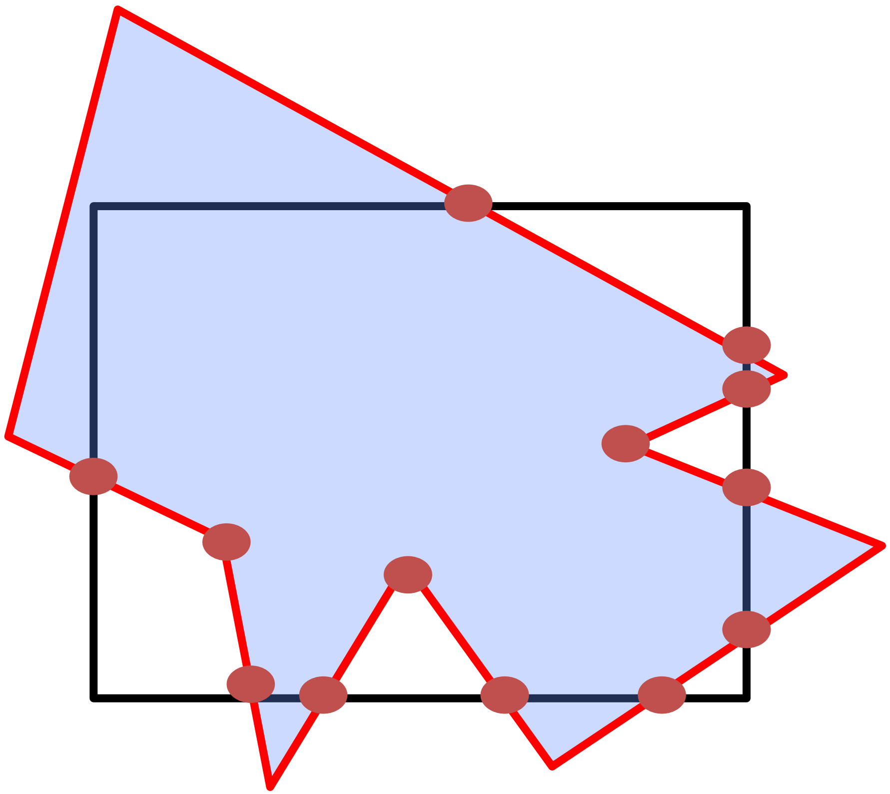


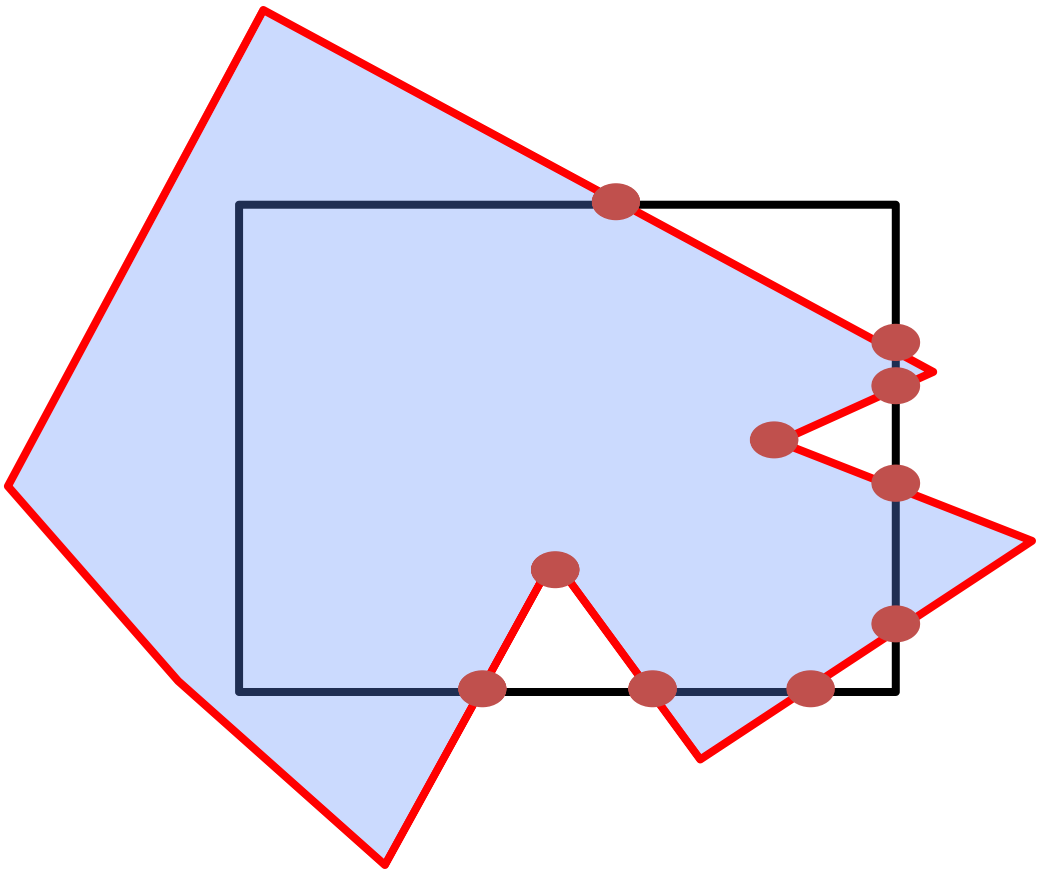
After Clipping

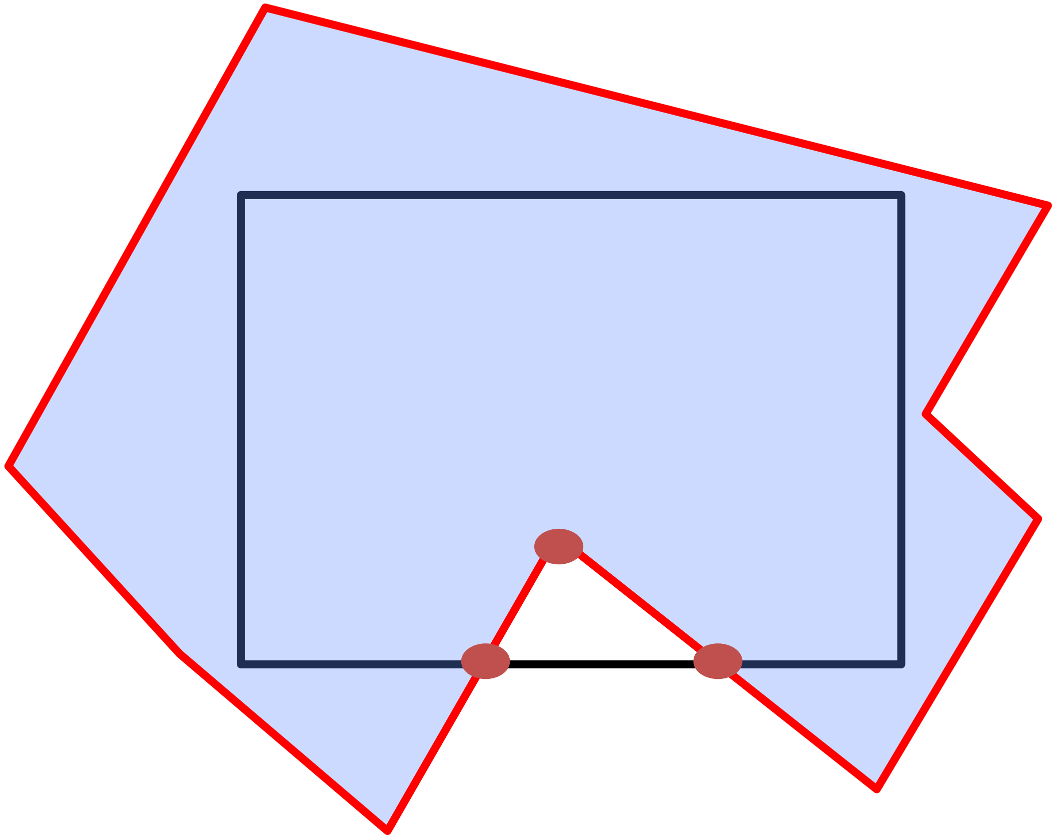


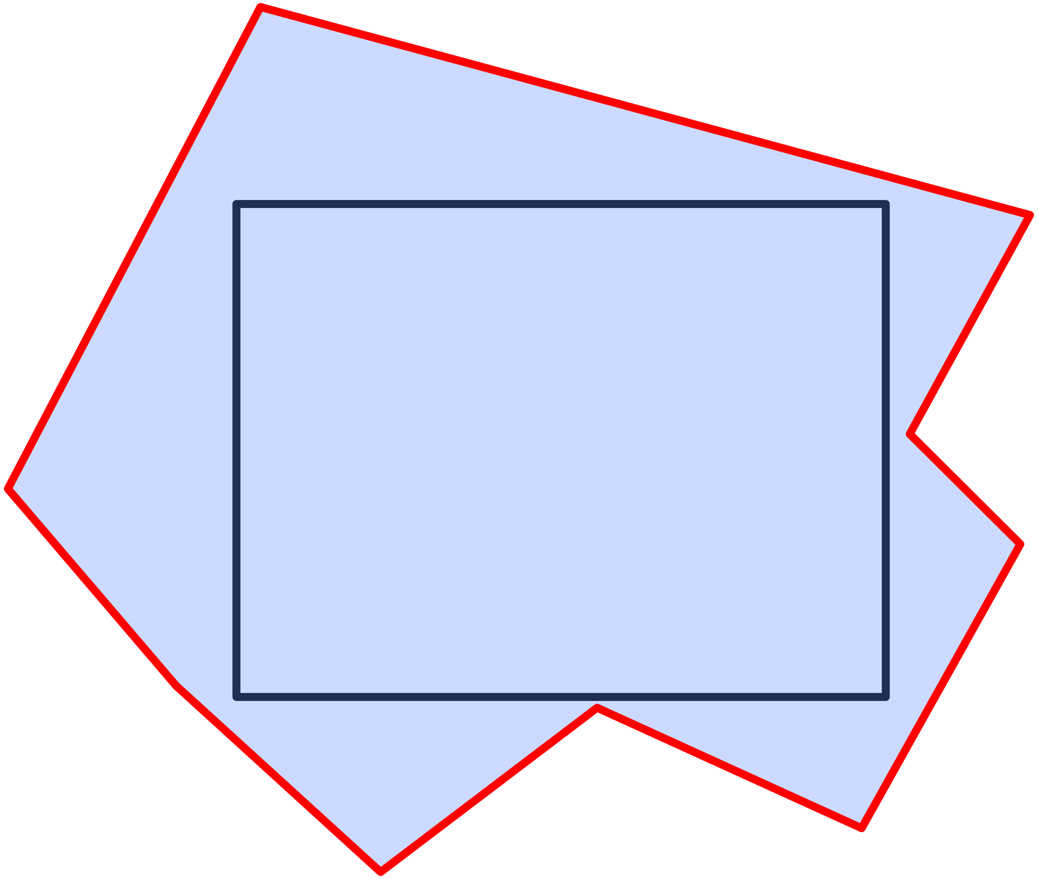






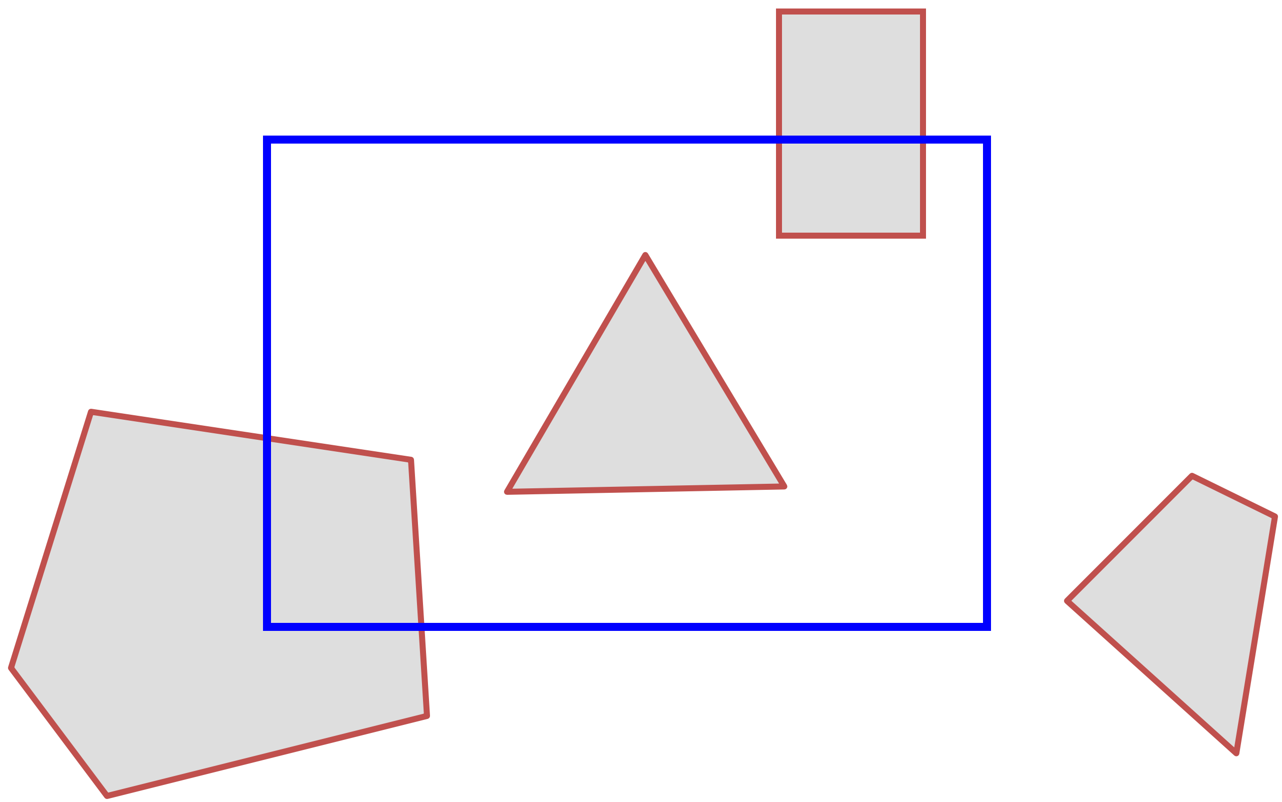






Sutherland Hodgeman Clipping

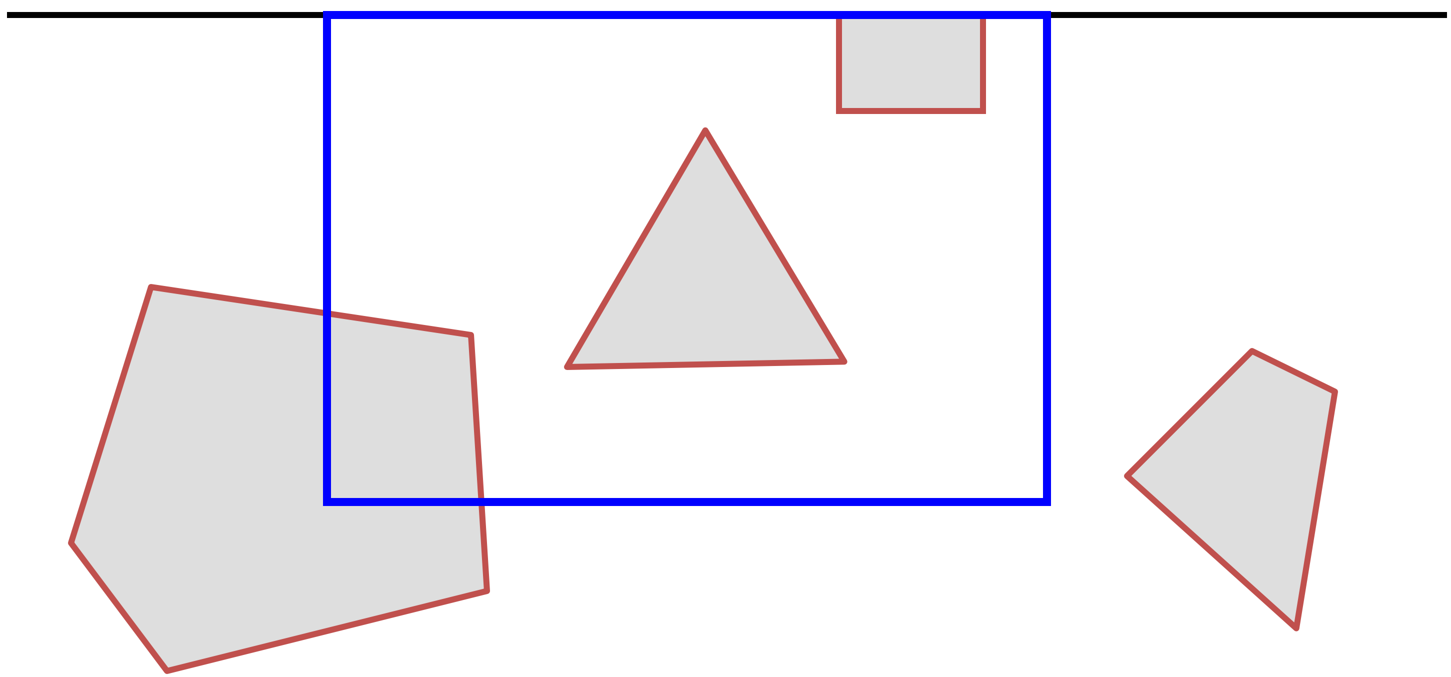
- Clip to each window boundary one at a time



After each clipping a new set of vertices is produced.

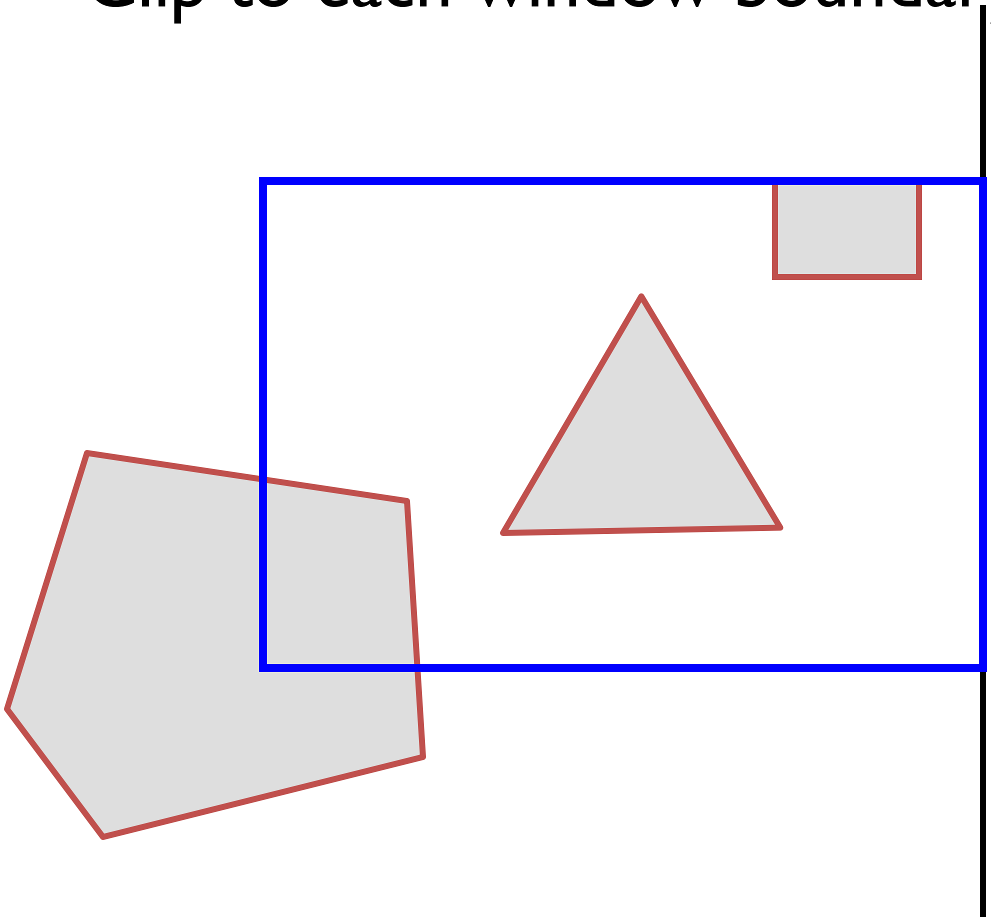
Sutherland Hodgeman Clipping

- Clip to each window boundary one at a time



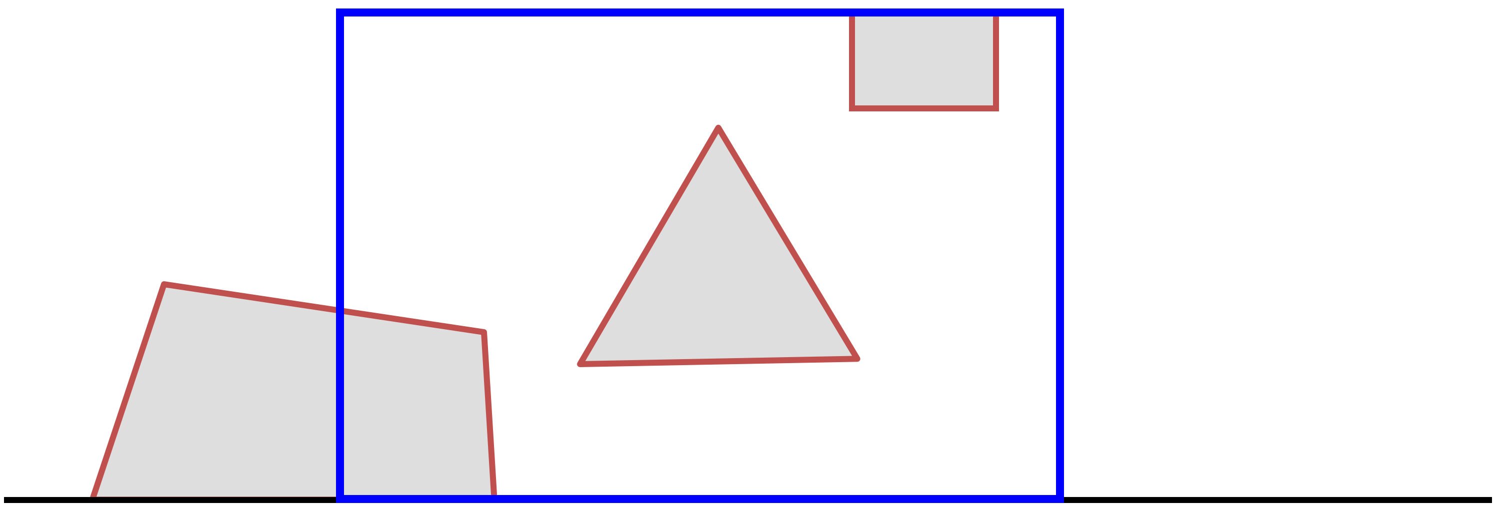
Sutherland Hodgeman Clipping

- Clip to each window boundary one at a time



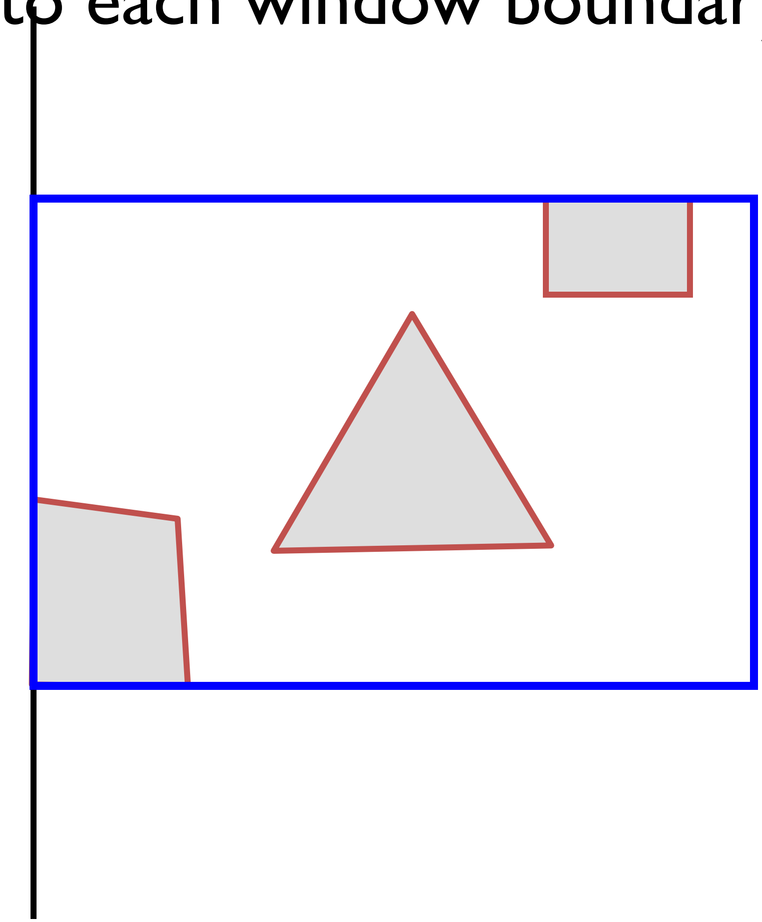
Sutherland Hodgeman Clipping

- Clip to each window boundary one at a time



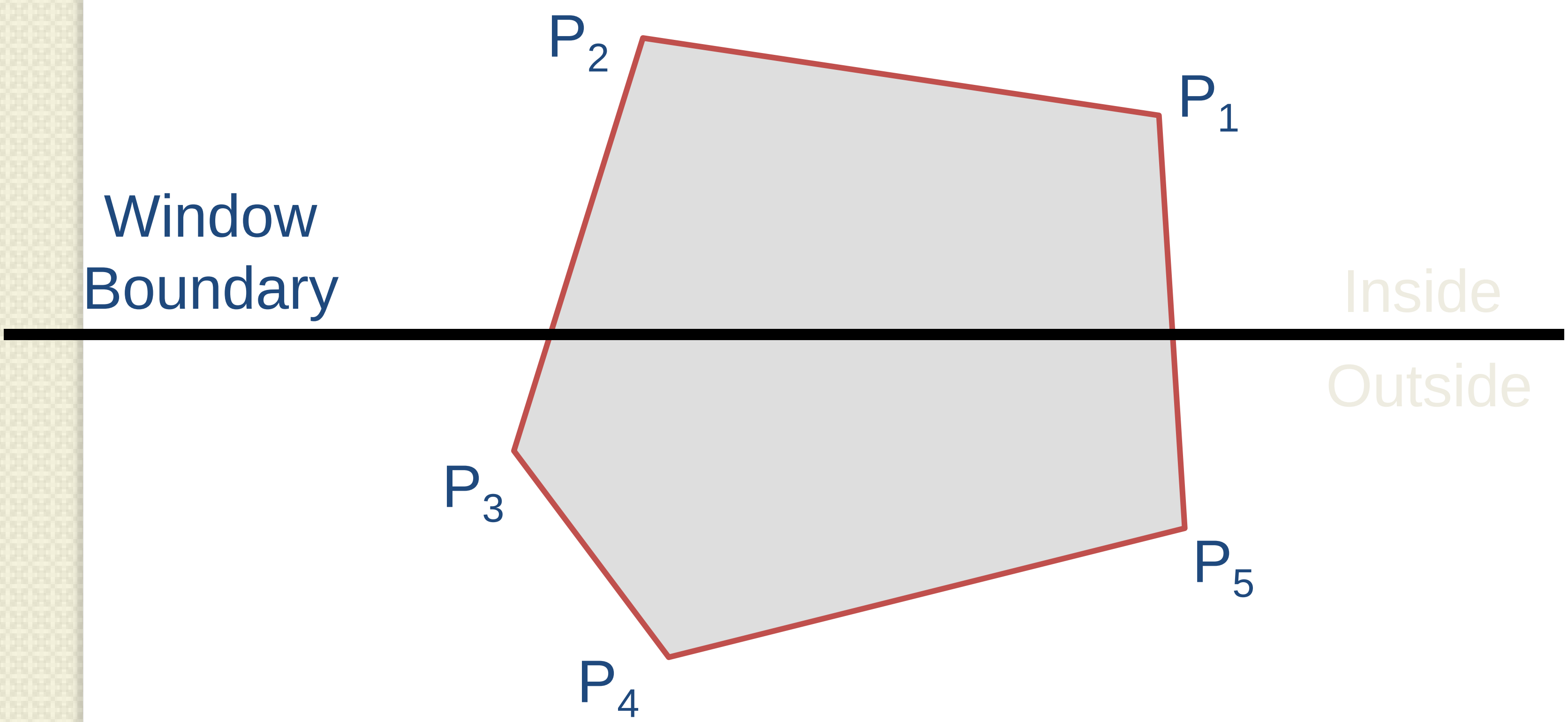
Sutherland Hodgeman Clipping

- Clip to each window boundary one at a time



Clipping to a Boundary

- Do inside test for each point in sequence,
  Insert new points when cross window boundary,
  Remove points outside window boundary



Clipping to a Boundary

- Do inside test for each point in sequence,
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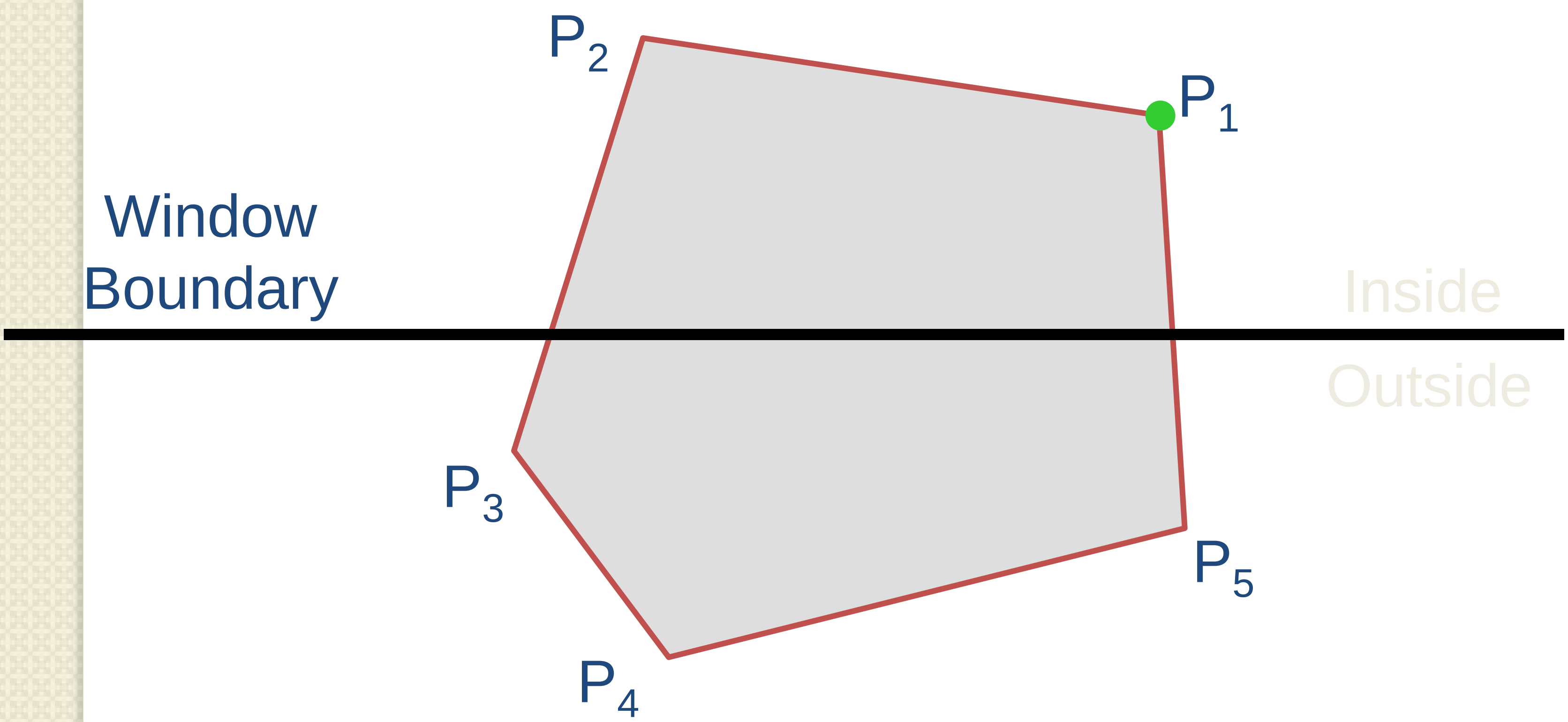
  Remove points outside window boundary



Clipping to a Boundary

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  Insert new points when cross window boundary,
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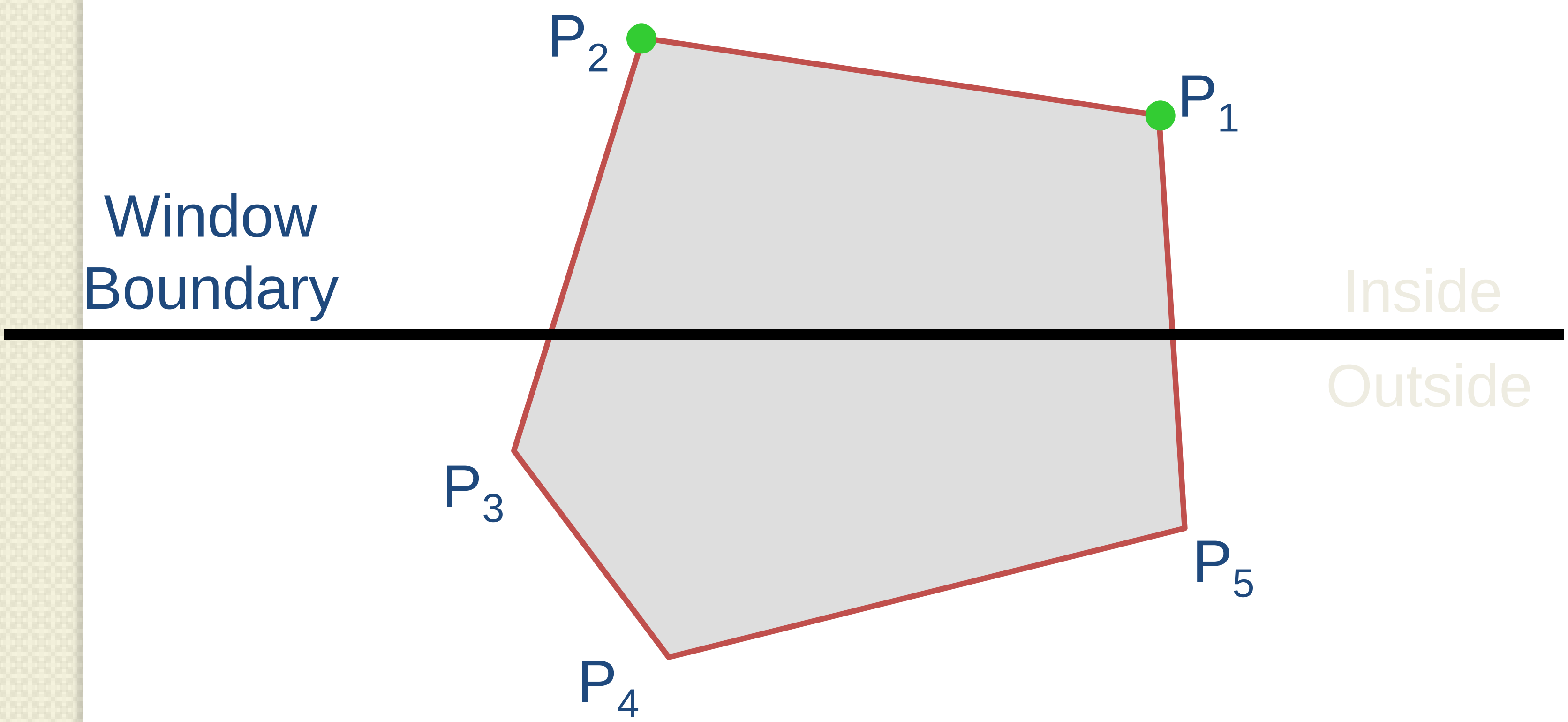
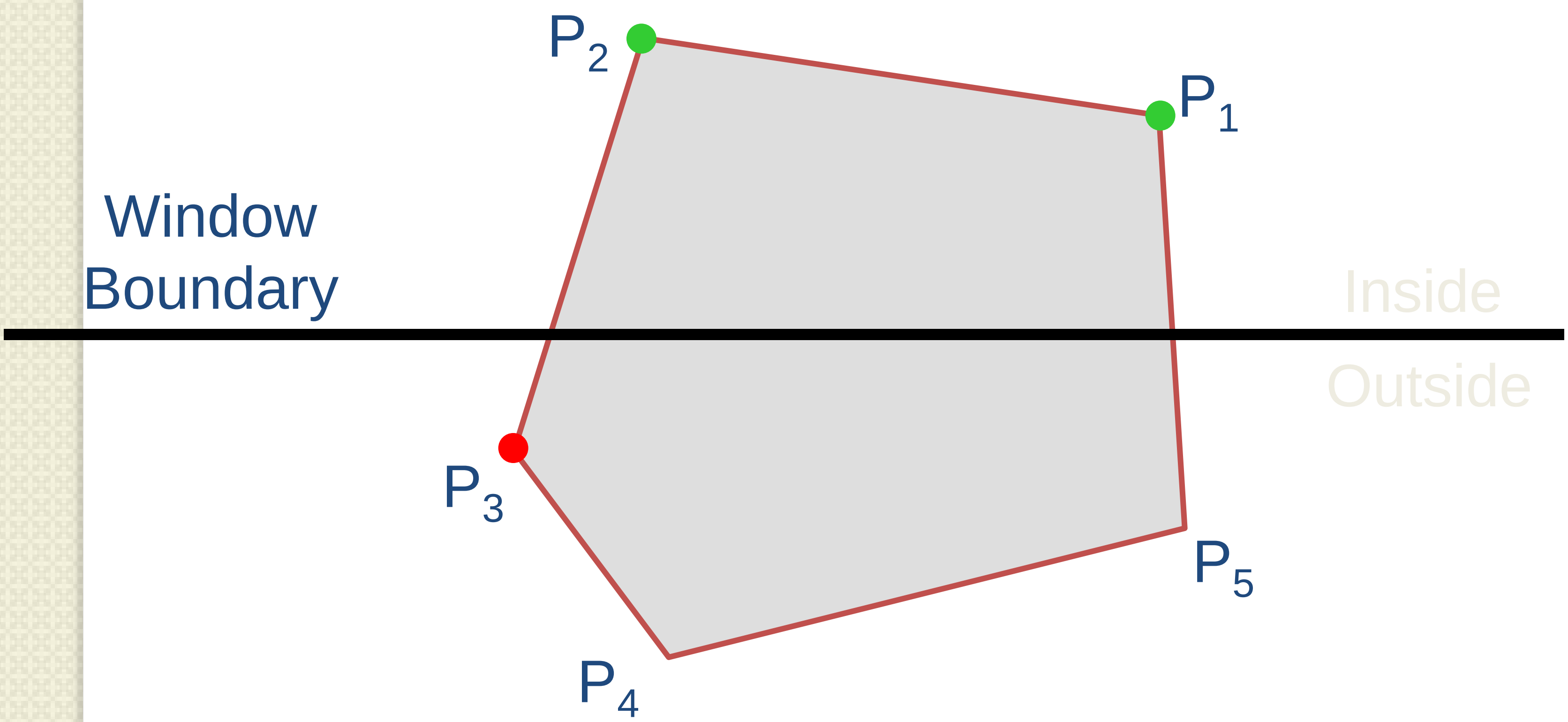


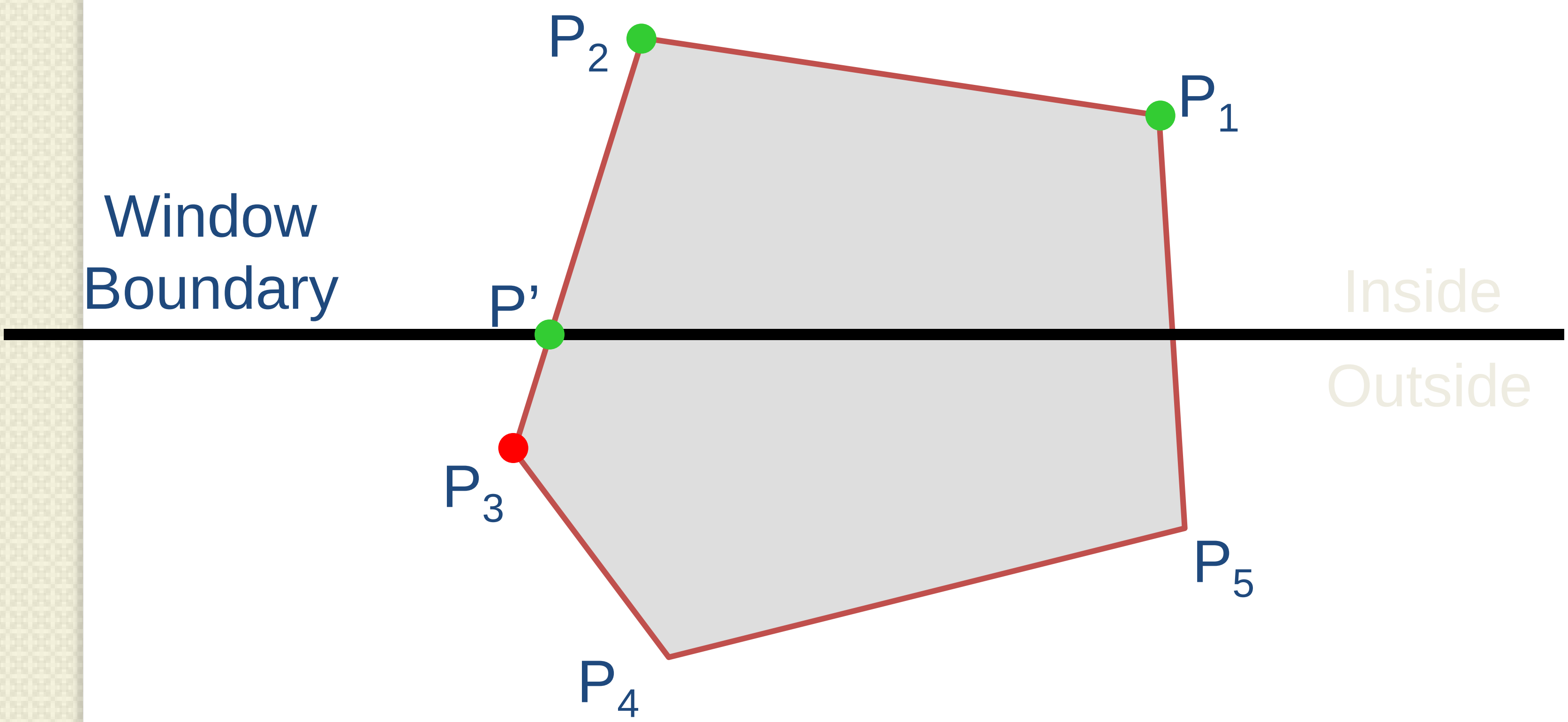
Clipping to a Boundary

- Do inside test for each point in sequence,
  Insert new points when cross window boundary,
  Remove points outside window boundary



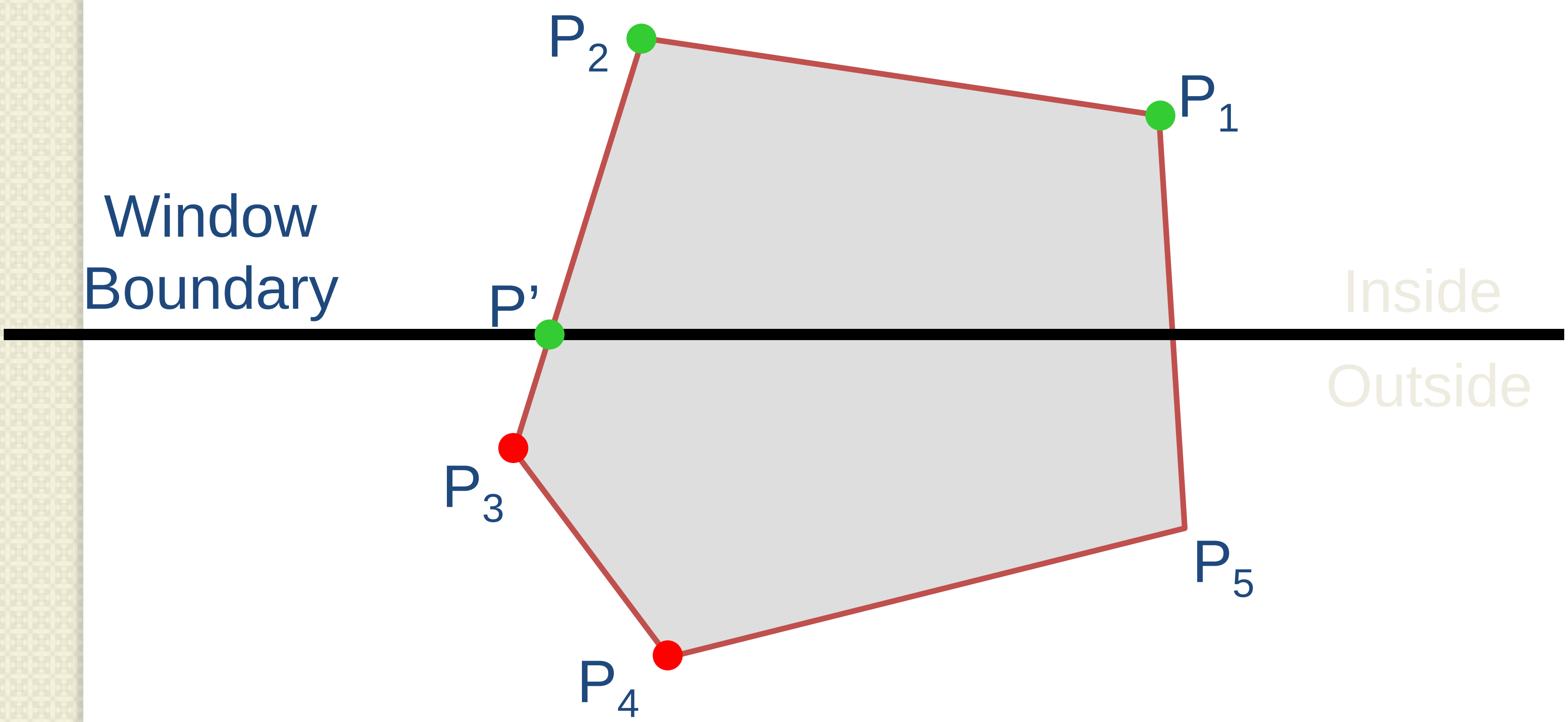
Clipping to a Boundary

- Do inside test for each point in sequence,
  Insert new points when cross window boundary,
  Remove points outside window boundary



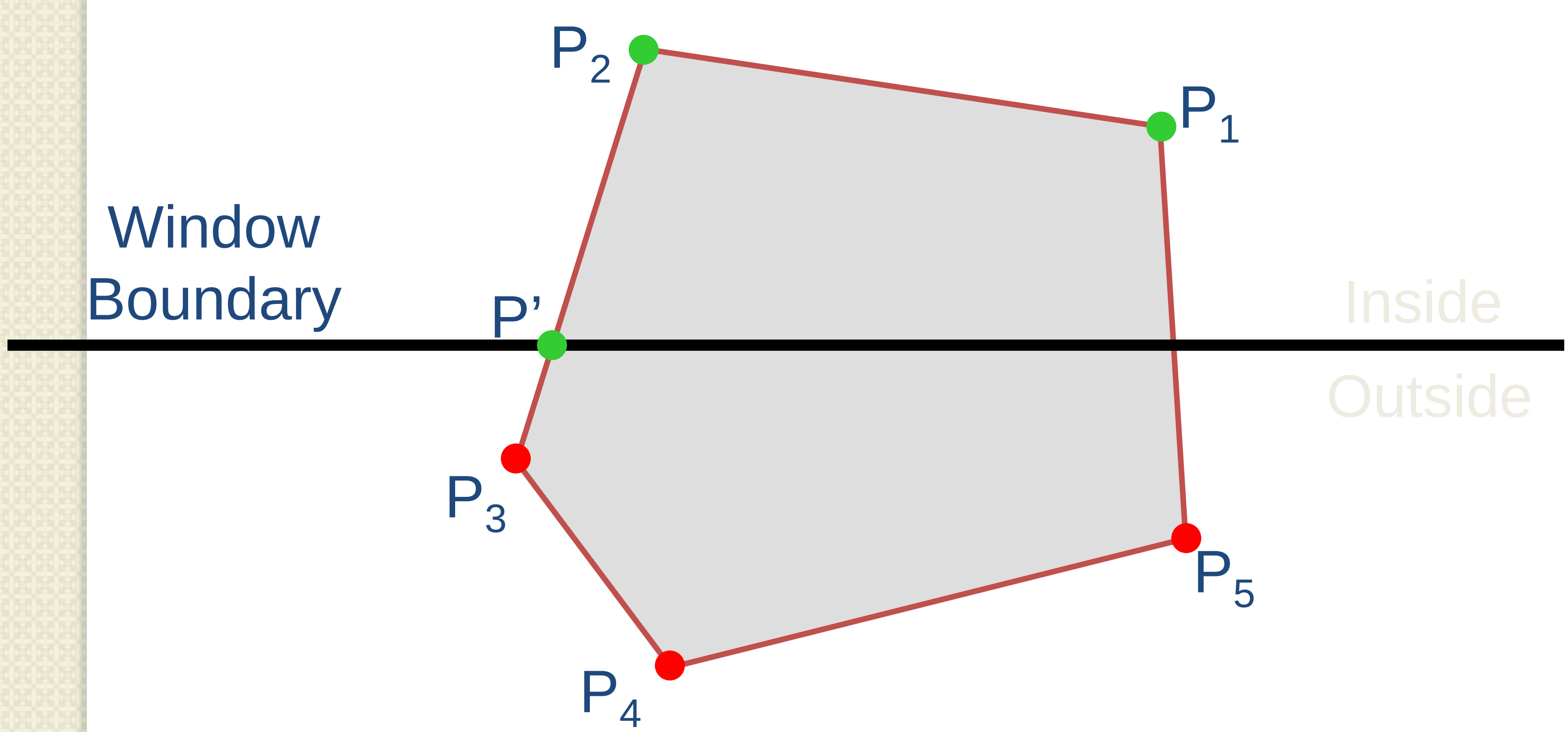
Clipping to a Boundary

- Do inside test for each point in sequence,
  Insert new points when cross window boundary,
  Remove points outside window boundary



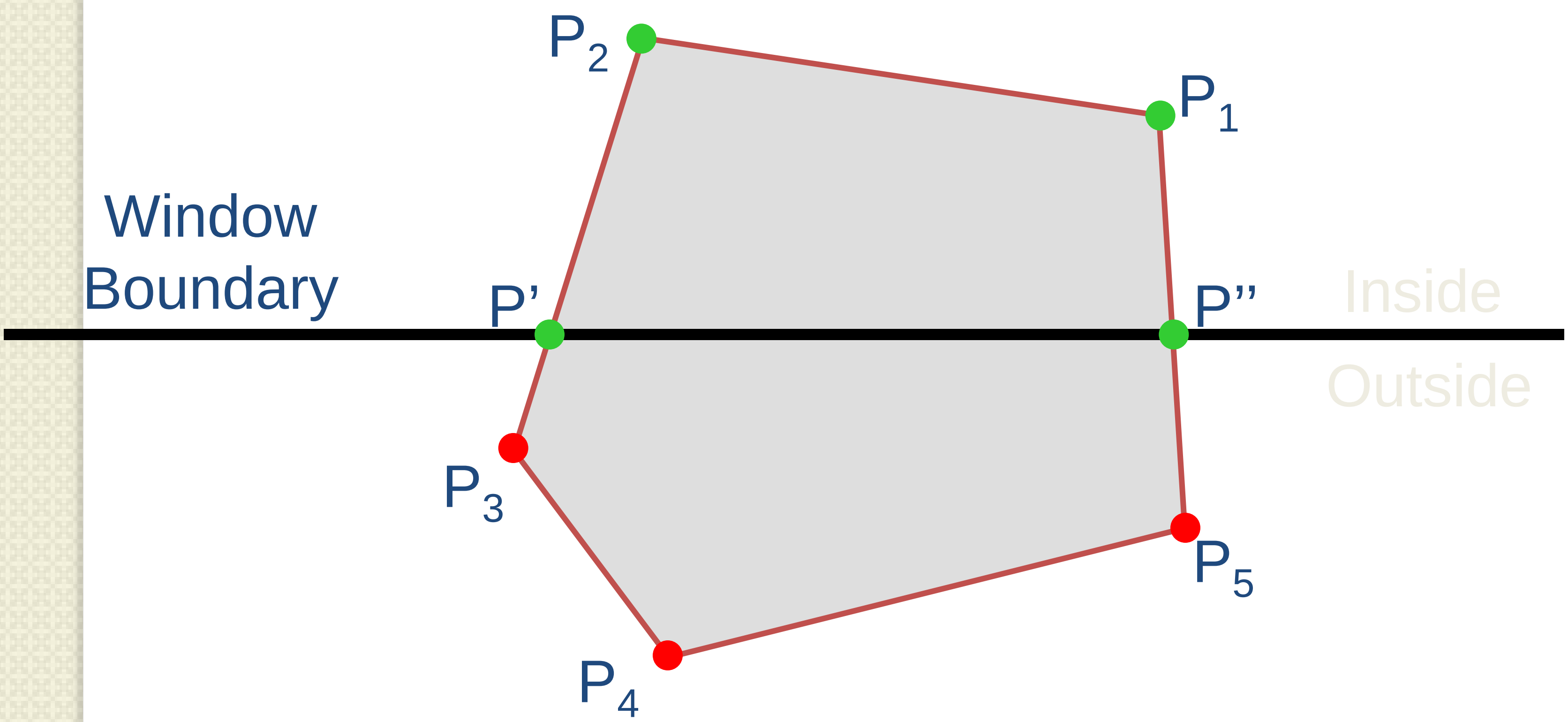
Clipping to a Boundary

- Do inside test for each point in sequence,
  Insert new points when cross window boundary,
  Remove points outside window boundary



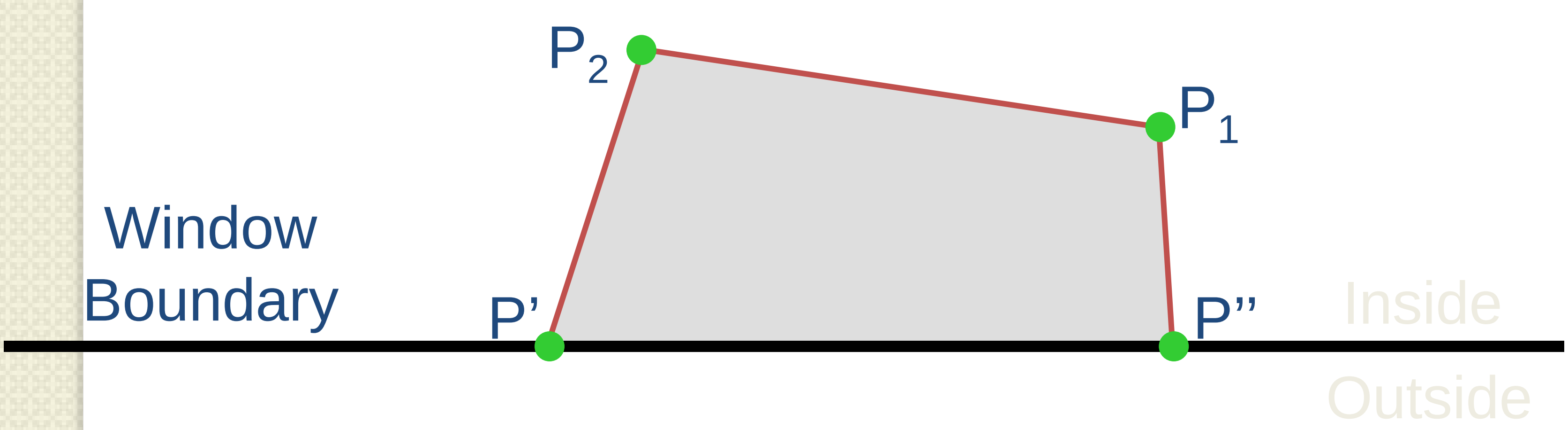
Clipping to a Boundary

- Do inside test for each point in sequence,
  Insert new points when cross window boundary,
  Remove points outside window boundary

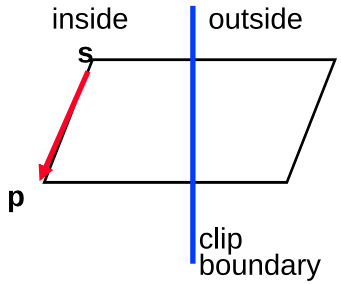


Clipping to a Boundary

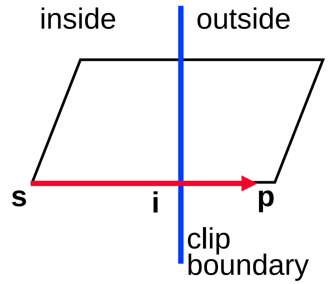
- Do inside test for each point in sequence,
  Insert new points when cross window boundary,
  Remove points outside window boundary



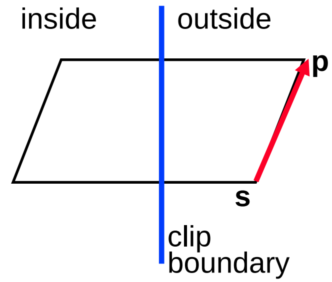
For each clip edge - consider the relation between successive vertices of the polygon; Assume vertex **s** has been dealt with, vertex **p** follows:



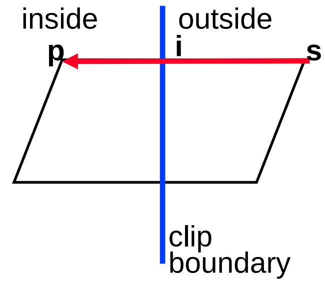
p added to output list



i added to output list



no output



i and **p** added to output list

Sutherland - Hodgman polygon Cliping Algoruthm

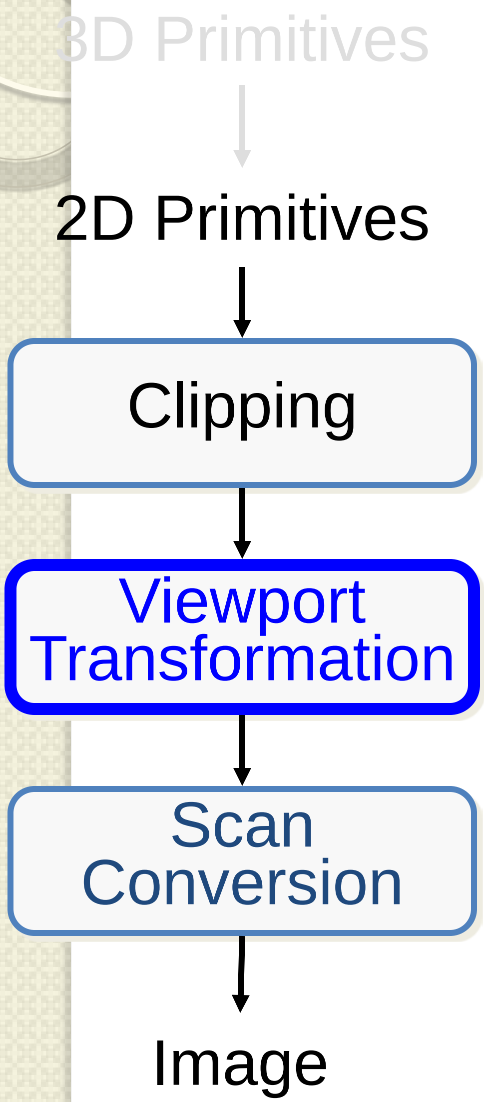
```
type
    vertex = point;        /* point holds real x, y */
    edge = array [1..2] of vertex;
    /* Max declared as constant */
    vertexArray = array [1..MAX] of vertex;

procedure SutherlandHodgmanPolygonClip (
inVertexArray: vertixArray;            /* input vertex array */
var outVertexArray: vertexArray;      /*output vertex array */
inLength: integer;        /* num of entries in inVertexArray */
var outLength:integer; /*num of entries in outVertexArray */
clipBoundary : edge                   /* Edge of clip polygon */
);
```

Sutherland - Hodgman (cont.)

```
var
    s, p        /* Start, End point of current polygon edge */
    i : vertix;  /* Intersection point with clip boundary */
    j : integer;                    /* vertex loop counter */
begin
    outLength :=0;
    s := inVertexArray [inLength];
   /* Start with the kast vertex in inVertexArray*/
   for  j:=1 to inLength do
        begin
             p := inVertexArray[j ];
             if  Inside (p, clipBoundary ) then
               if  Inside (s, clipBoundary ) then
                 Output (p,outLength, outVertexArray) /*case #1*/
              else
                begin     /* case # 4 */
                  Intersect (s, p, clipBoundary, i);
                  Output (i, outLength, outVertexArray );
                  Output (p, outLength, outVertexArray );
               end
             else
              if  Inside (s, clipBoundary ) then
                begin      /* case # 2 */
                   Intersect (s, p, clipBoundary, i );
                  Output (i, outLength, outVertexArray );
               end;
        s := p ;            /* Advance to next pair of vertices */
         end    /* for */
end;        /* SutherlandHodgmanPolygonClip */
```

2D Rendering Pipeline



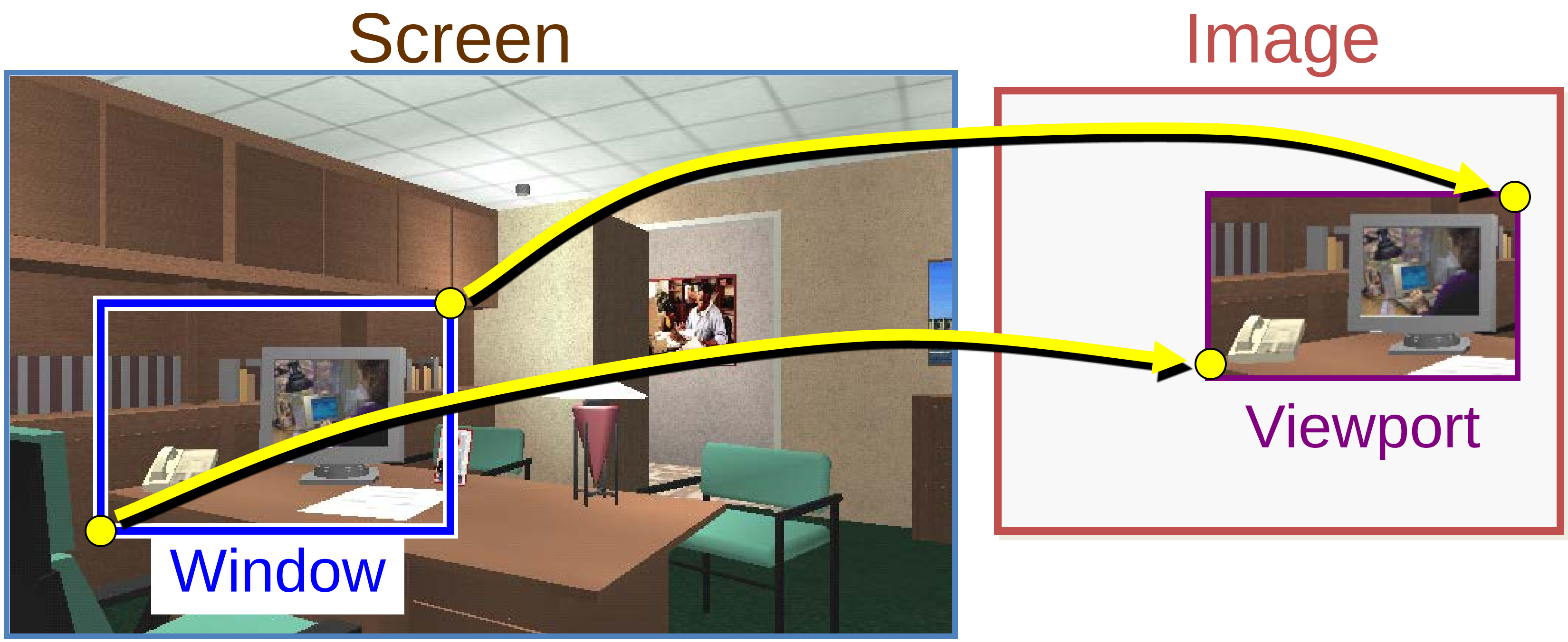
Clip portions of geometric primitives residing outside the window

Transform the clipped primitives from screen to image coordinates

Fill pixels representing primitives in screen coordinates

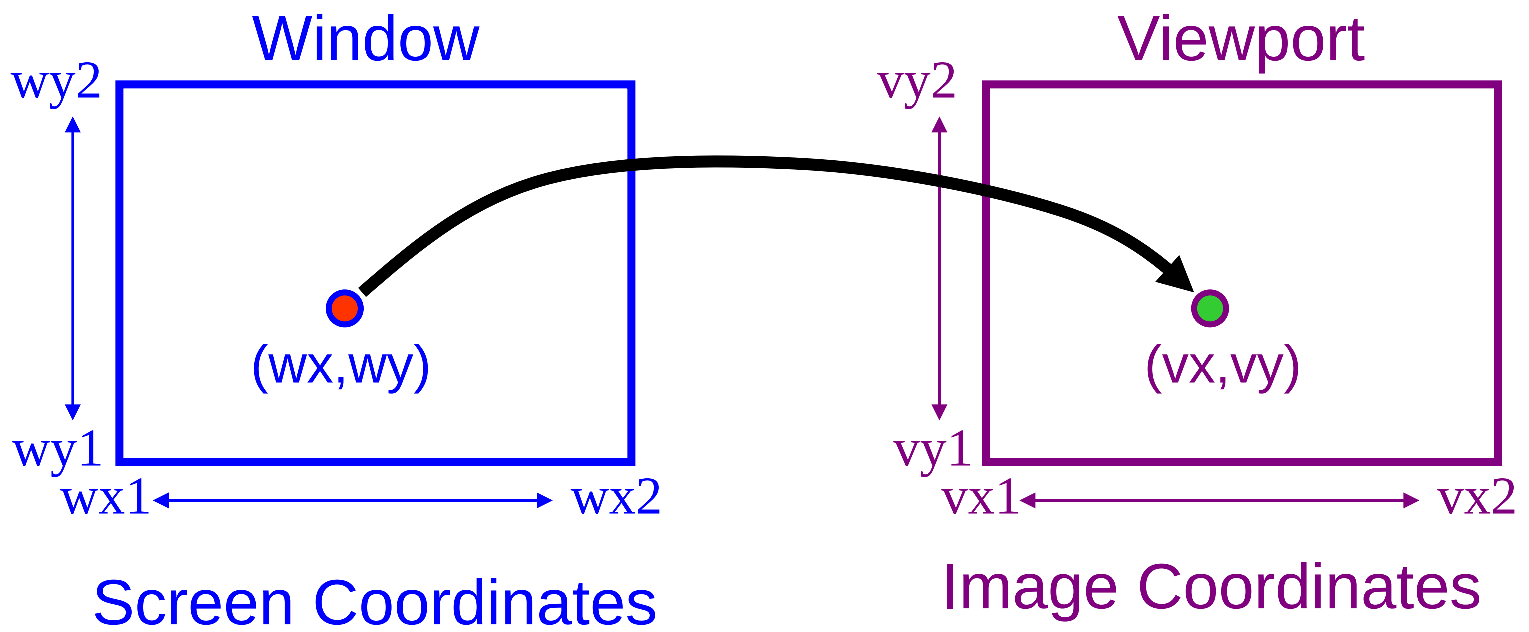
Viewport Transformation

- Transform 2D geometric primitives from screen coordinate system (normalized device coordinates) to image coordinate system (pixels)



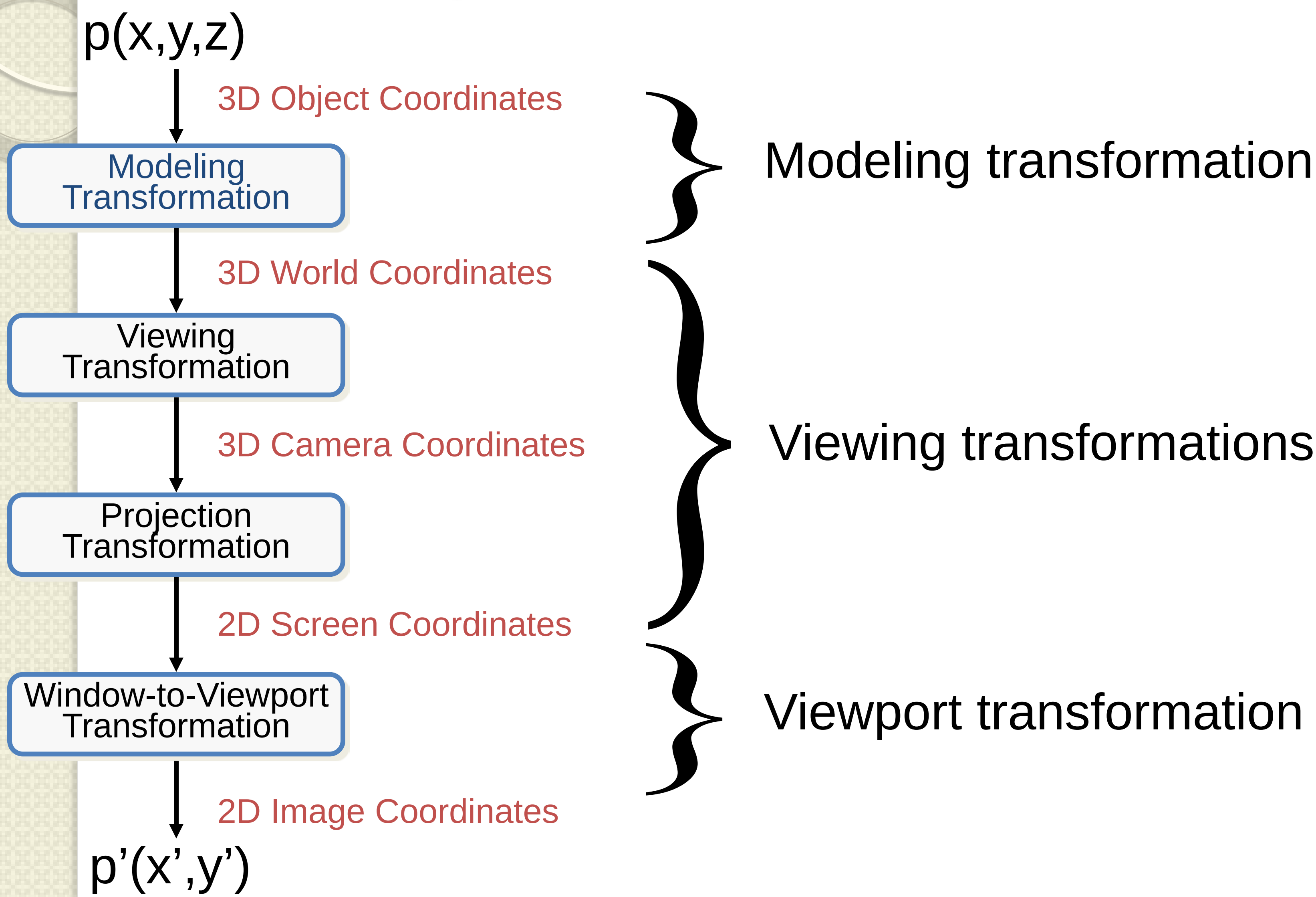
Viewport Transformation

- Window-to-viewport mapping

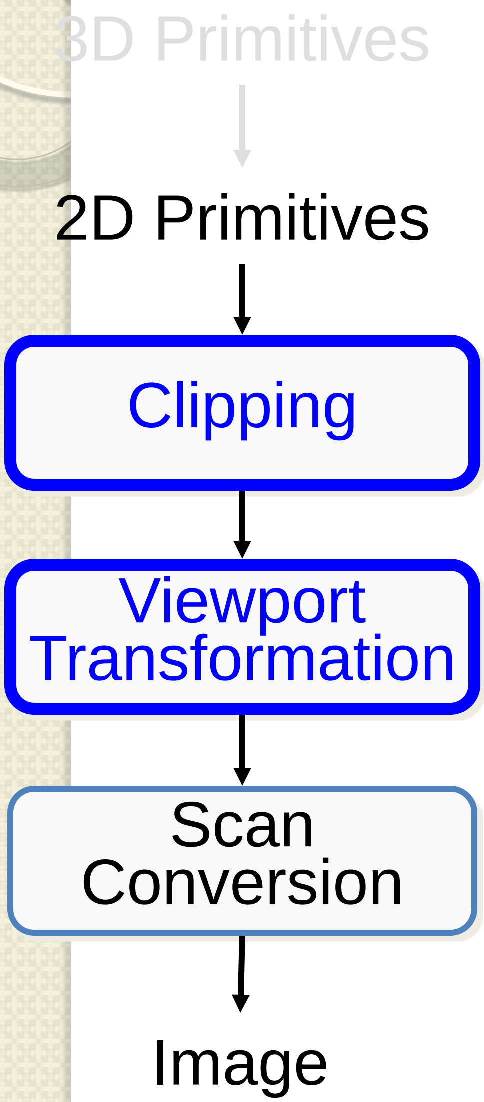



```
vx = vx1 + (wx - wx1) * (vx2 - vx1) / (wx2 - wx1);
vy = vy1 + (wy - wy1) * (vy2 - vy1) / (wy2 - wy1);
```

Summary of Transformations



Summary

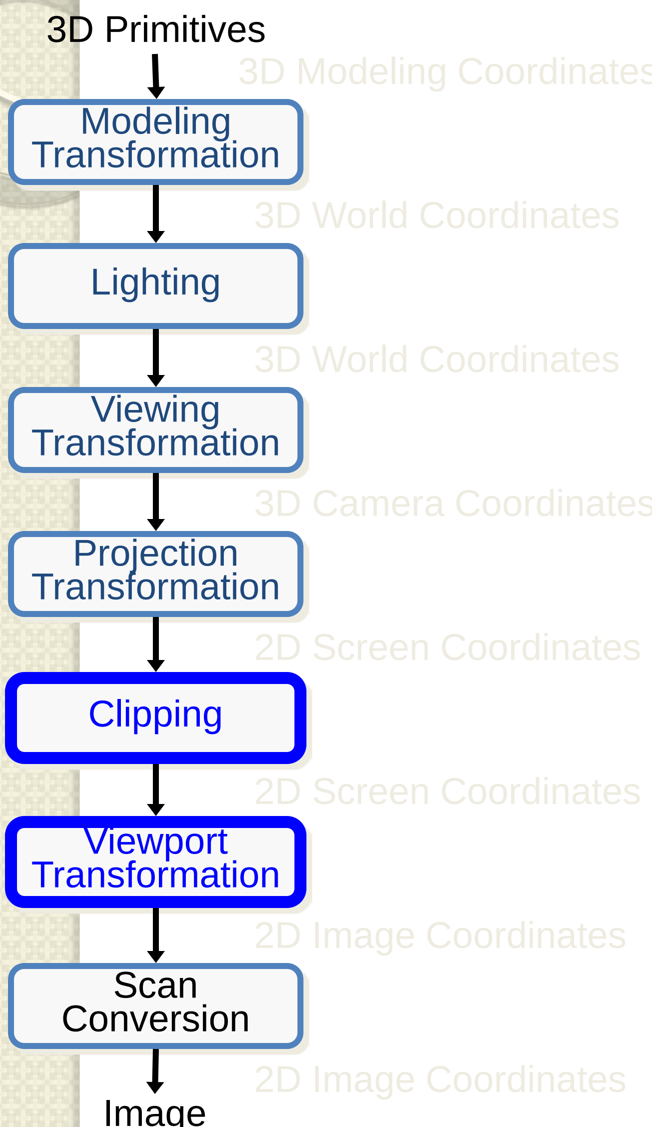


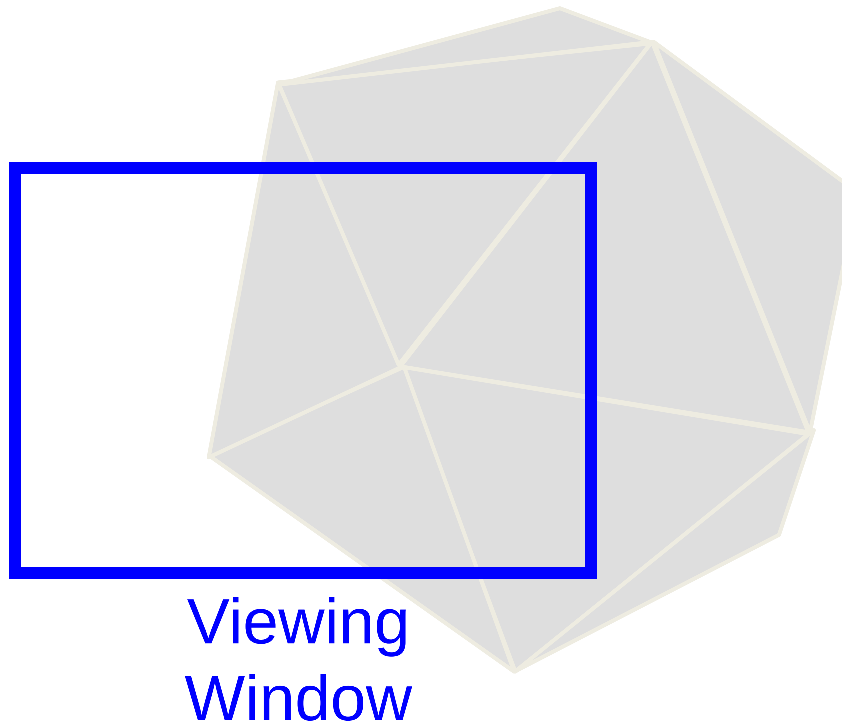
Clip portions of geometric primitives residing outside the window

Transform the clipped primitives from screen to image coordinates

Fill pixels representing primitives in screen coordinates

Summary


3D Primitives
3D Modeling Coordinates
Modeling Transformation
3D World Coordinates
Lighting
3D World Coordinates
Viewing Transformation
3D Camera Coordinates
Projection Transformation
2D Screen Coordinates
Clipping
2D Screen Coordinates
Viewport Transformation
2D Image Coordinates
Scan Conversion
2D Image Coordinates
Image


Viewing Window