Low level graphics software

- Points, lines and pixel-level things.
- A bit of history and some useful techniques

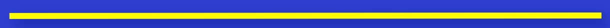
Line and poly-lines

Drawline 0 0 1 0 √

Drawline 1 0 1 1

Drawline 1 1 0 1

Drawline 0 1 0 0



Line and poly-lines

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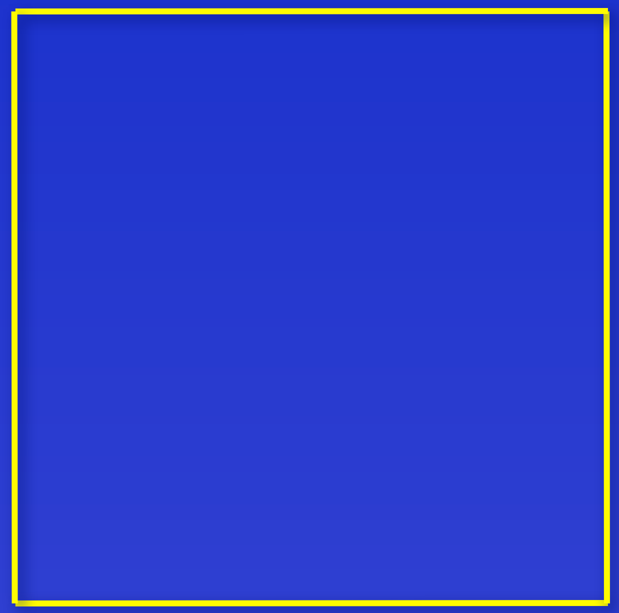
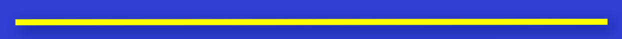


Poly-lines

```
glBegin(GL_LINES);
glVertex2i(0, 0);
glVertex2i(1, 0);    √
glVertex2i(1, 1);
glVertex2i(0, 1);
glVertex2i(0, 0);
```



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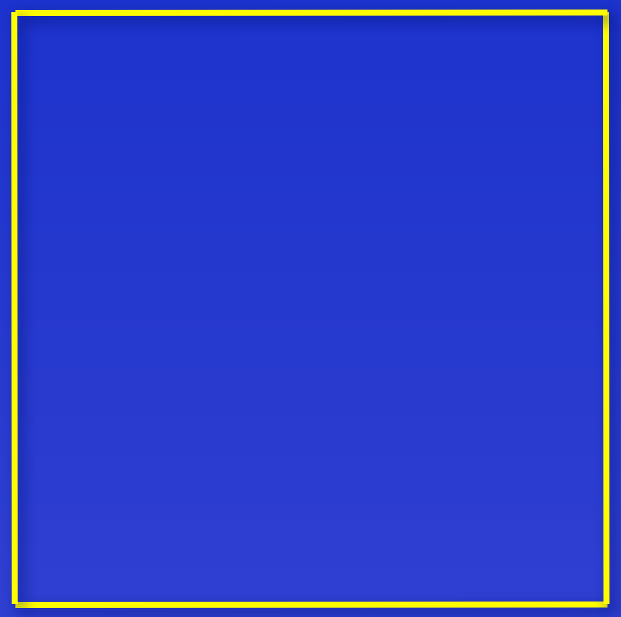
```

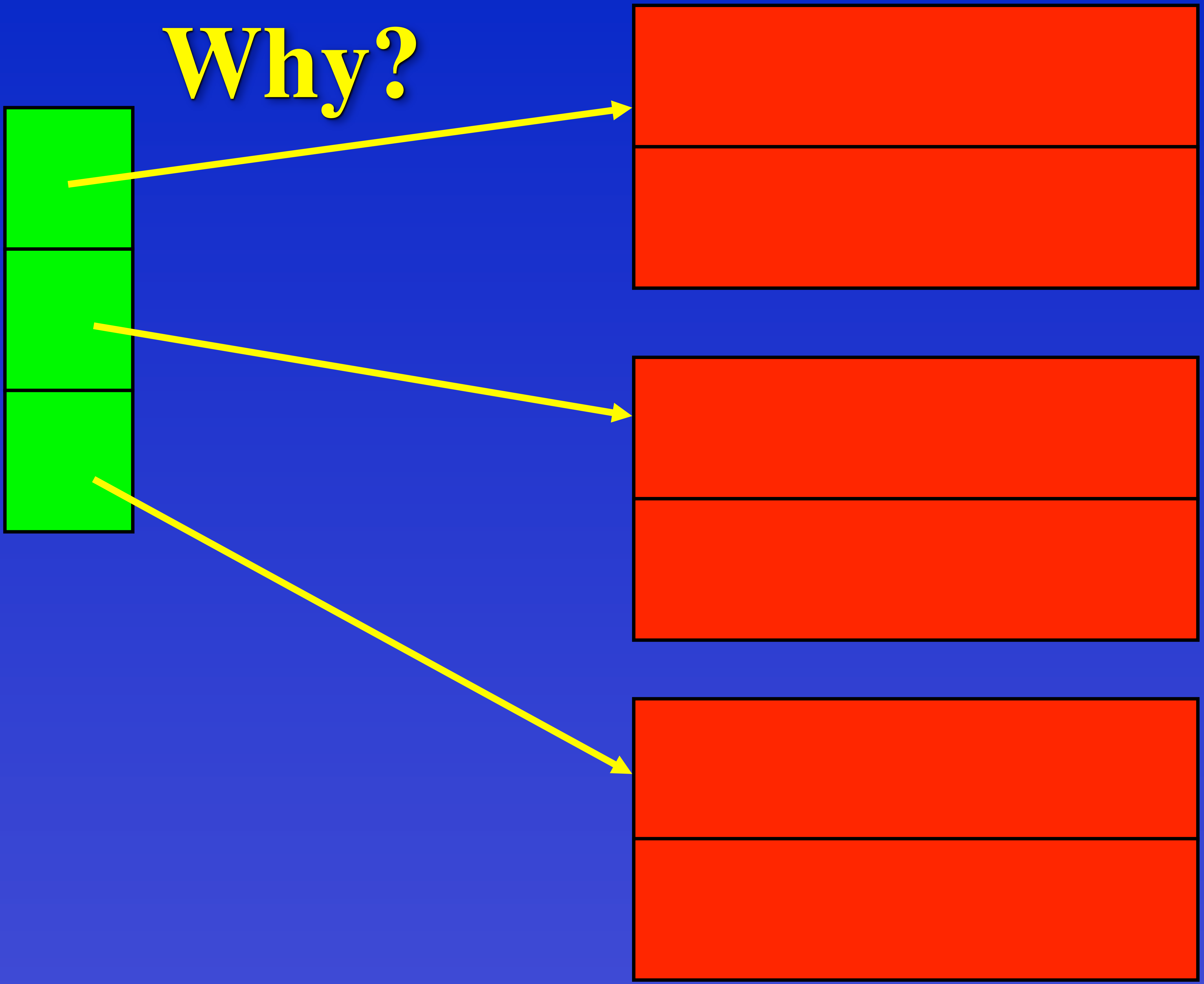


Polygon data structure

```
typedef struct { double x, y; } point;
typedef point *triangle[3];
```

```
Type point = record x, y: real end;
        pstore = ^point;
        triangle = array [1 .. 3] of pstore;
```

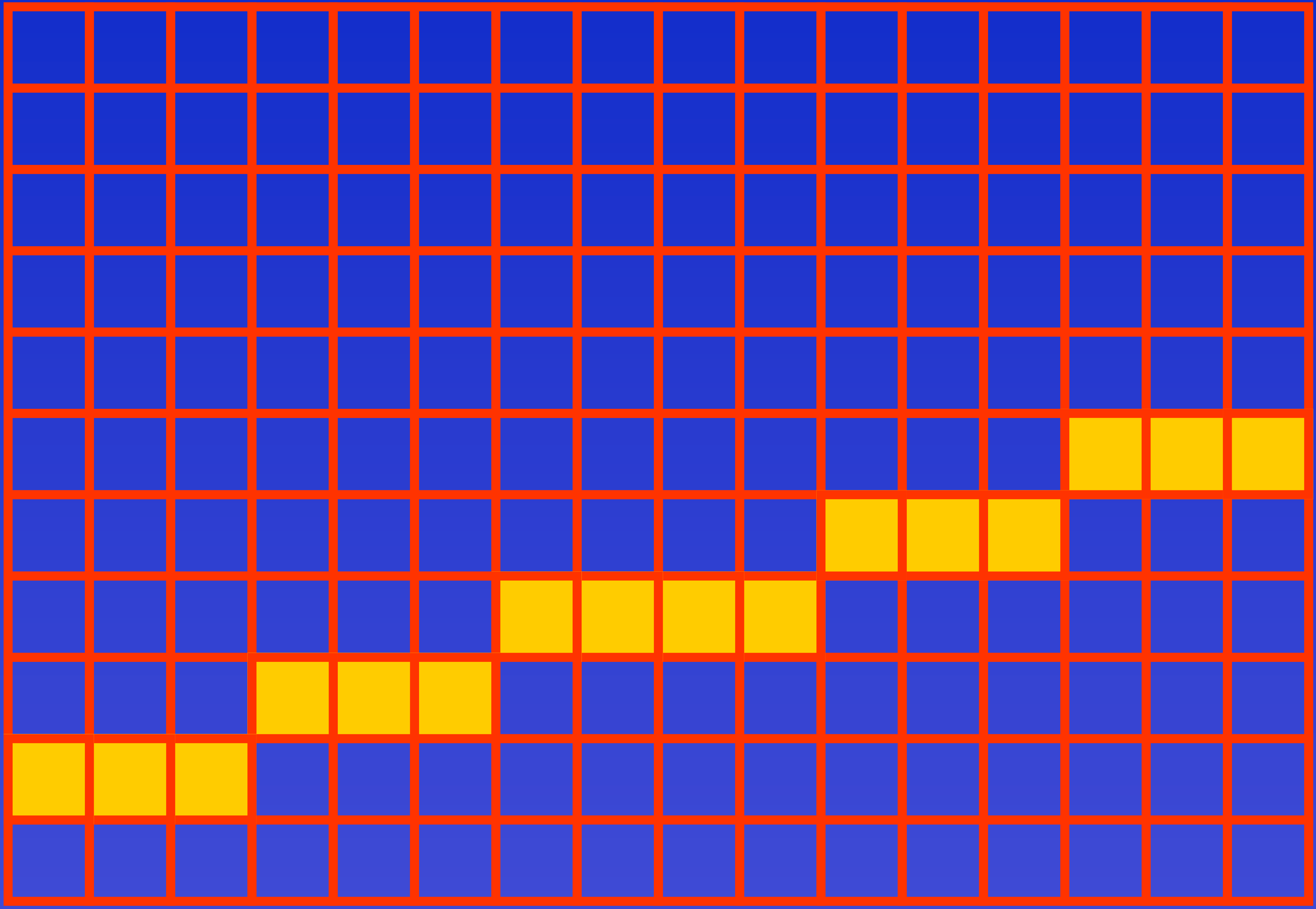
Why?



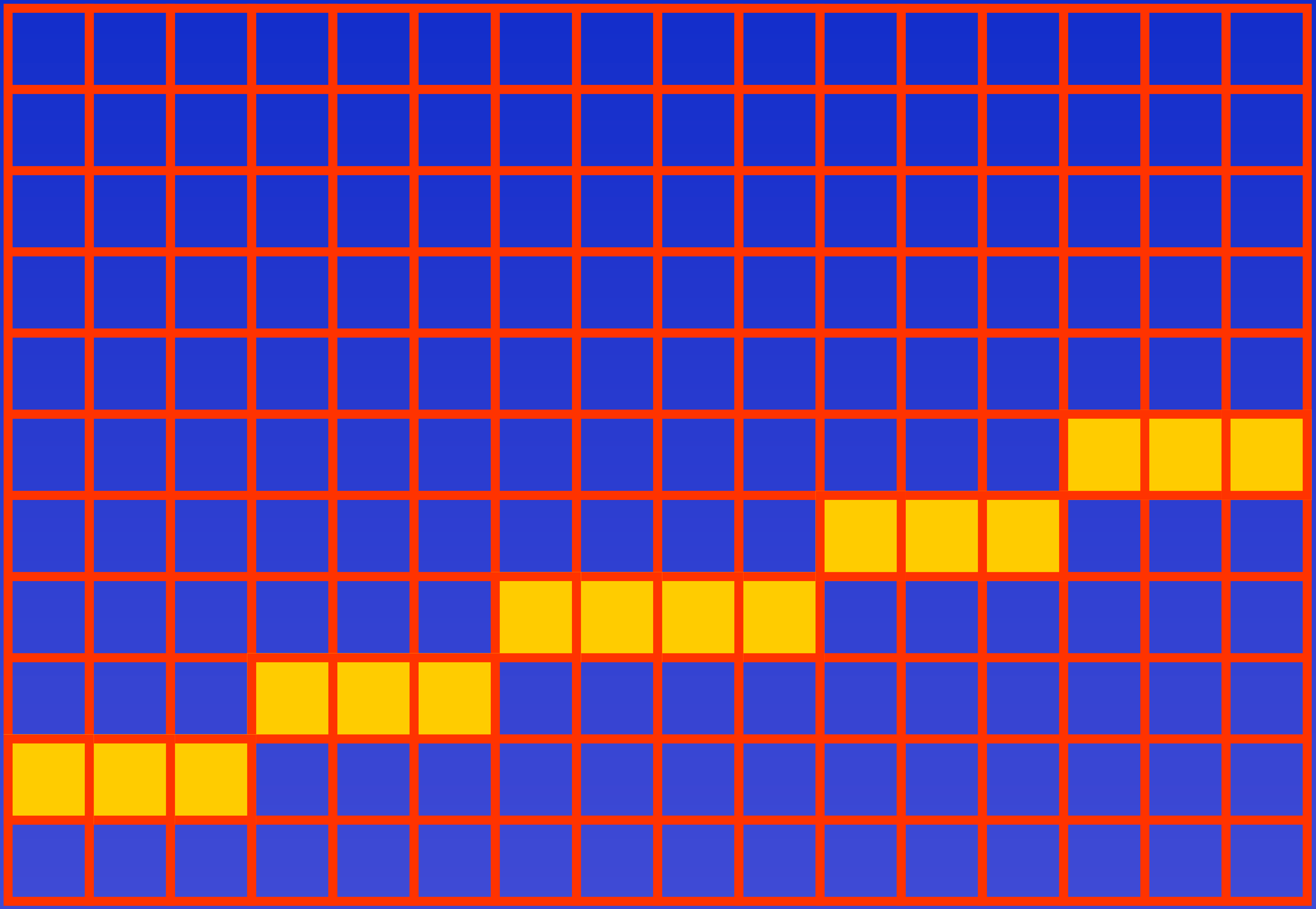
Why not arrays of vertices?

- Pointers are smaller than vertices.
- Each vertex appears only once.
- The same vertex can appear logically in more than one triangle.

Drawing lines at the pixel level



16 x 5 Pixel Example



How Lines are Drawn

- So we increment y every 16/5 steps
- But 16/5 is not a whole number
- How do we choose the best pattern?

Bresenham 1965

- Use relative coordinates
  - solve restricted problem first

- rx >= ry and ry >= 0
- use running error d
- every loop d := d - ry; x := x+1;
- sometimes d := d + rx; y := y+1;

```
d = rx / 2;
incr = rx - ry;
for (i = 1; i <= rx; i++)
{   x = x+1;
    if (d < ry)
    {   y = y+1;
        d = d+incr;
    } else
        d = d - ry;
    pixel[x] [y] = colour;
}
```

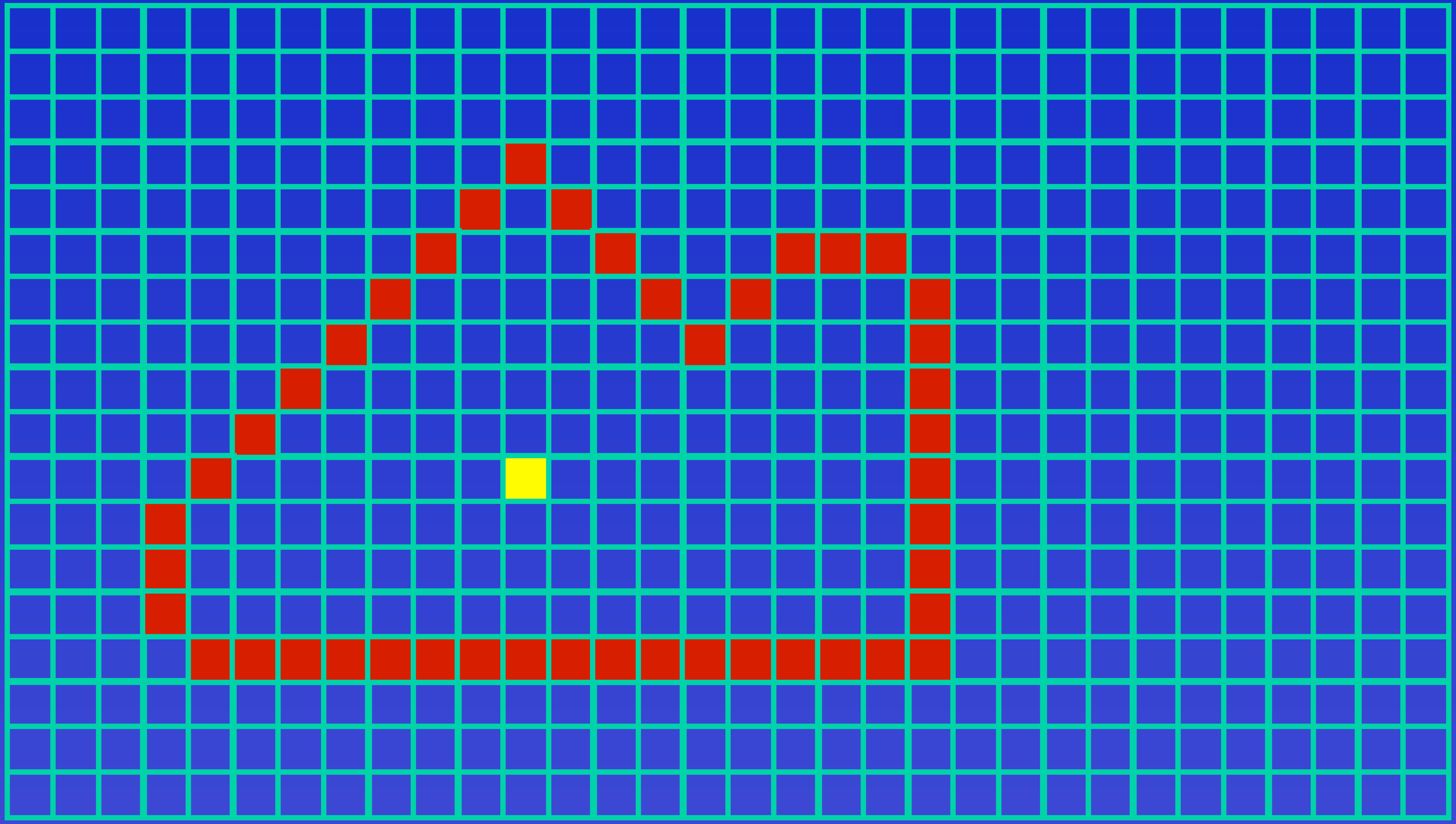
How does it work?

- Basically doing division by repeated subtraction operations.
- d is a running error term. Whenever the error is big enough we do ++y and thus reduce the error.

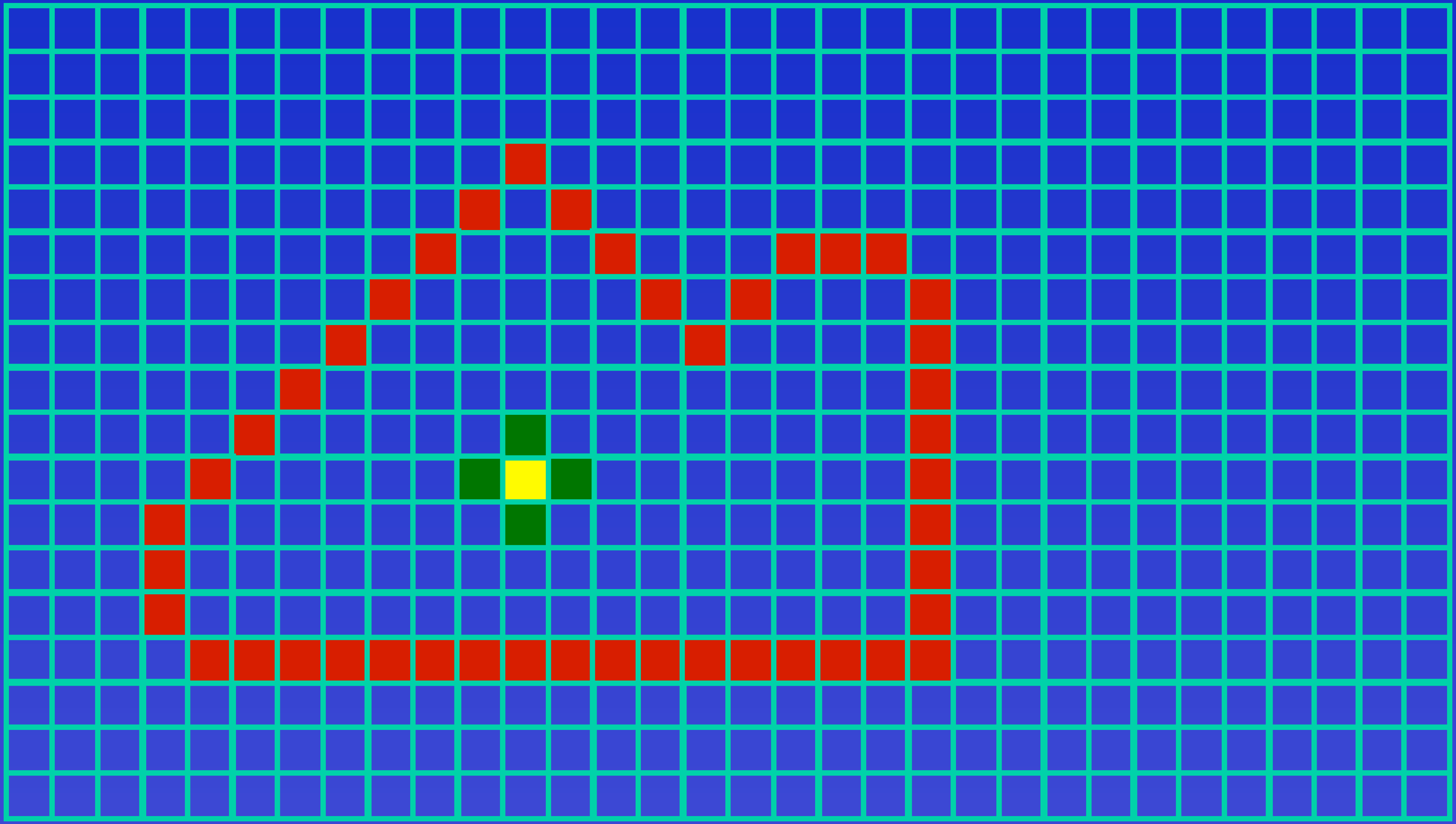
Filled Shapes

- We look at two approaches:
  - Flood Filling
  - Scan lines

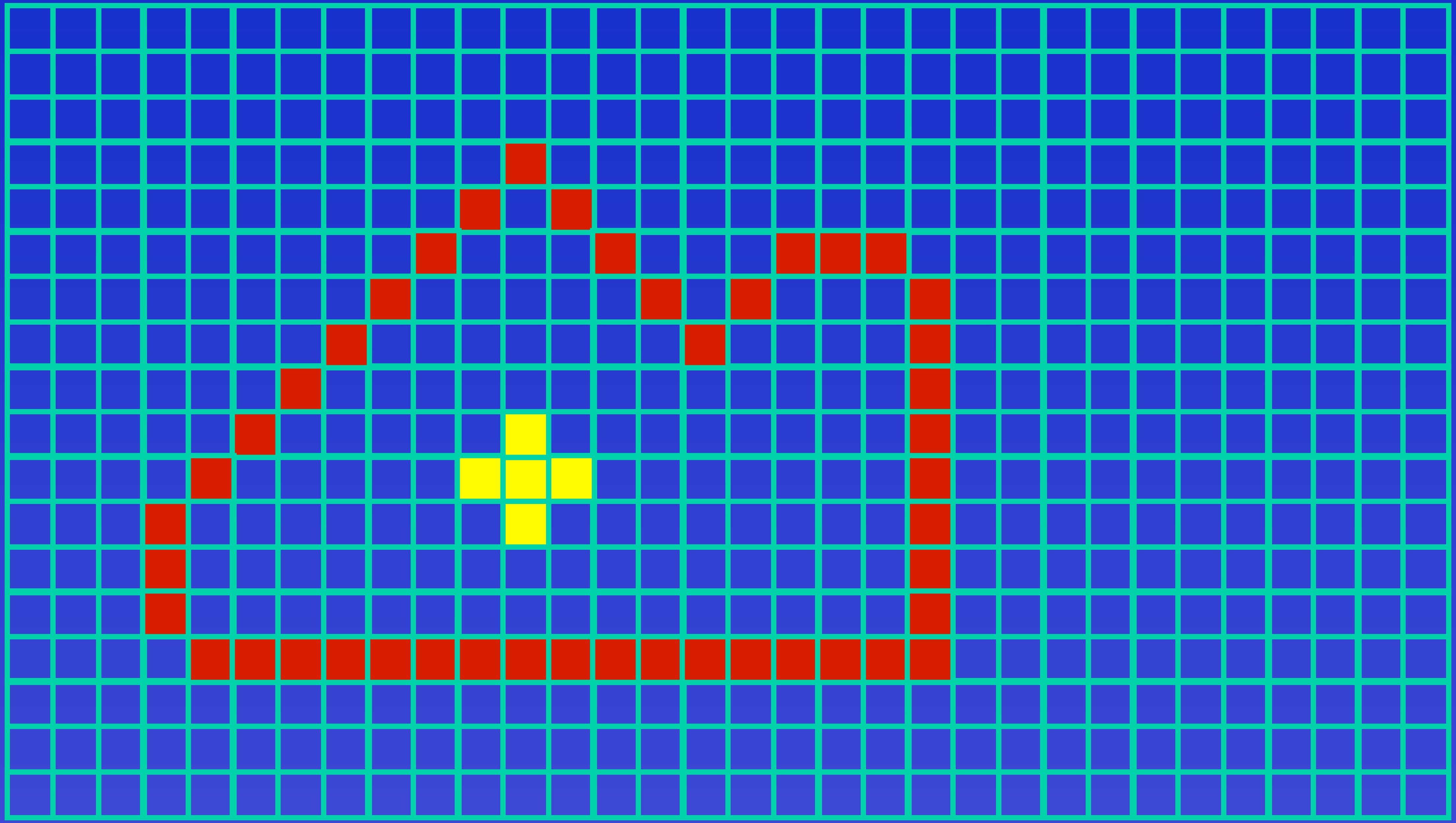
Flood Filling



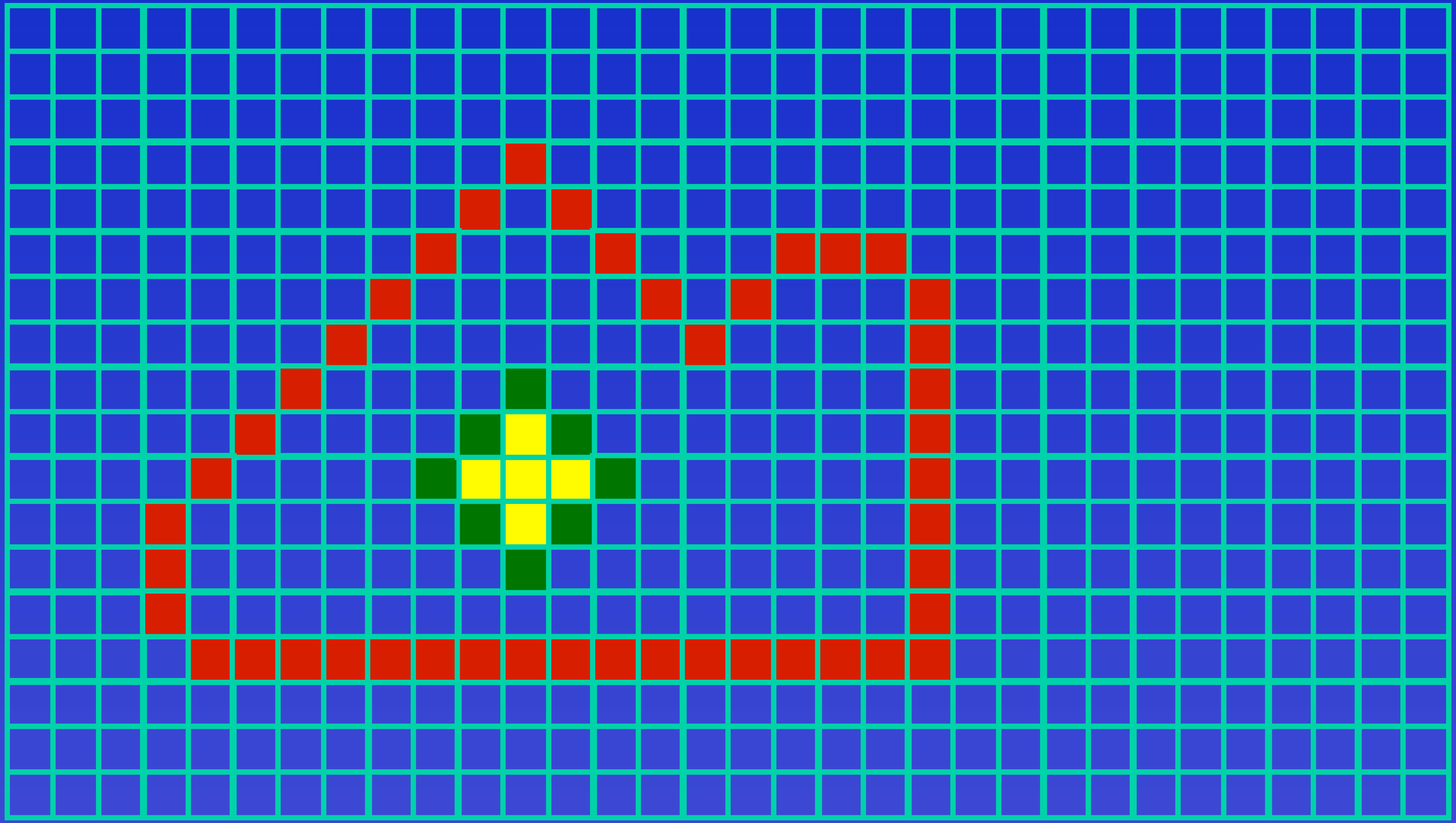
Flood Filling



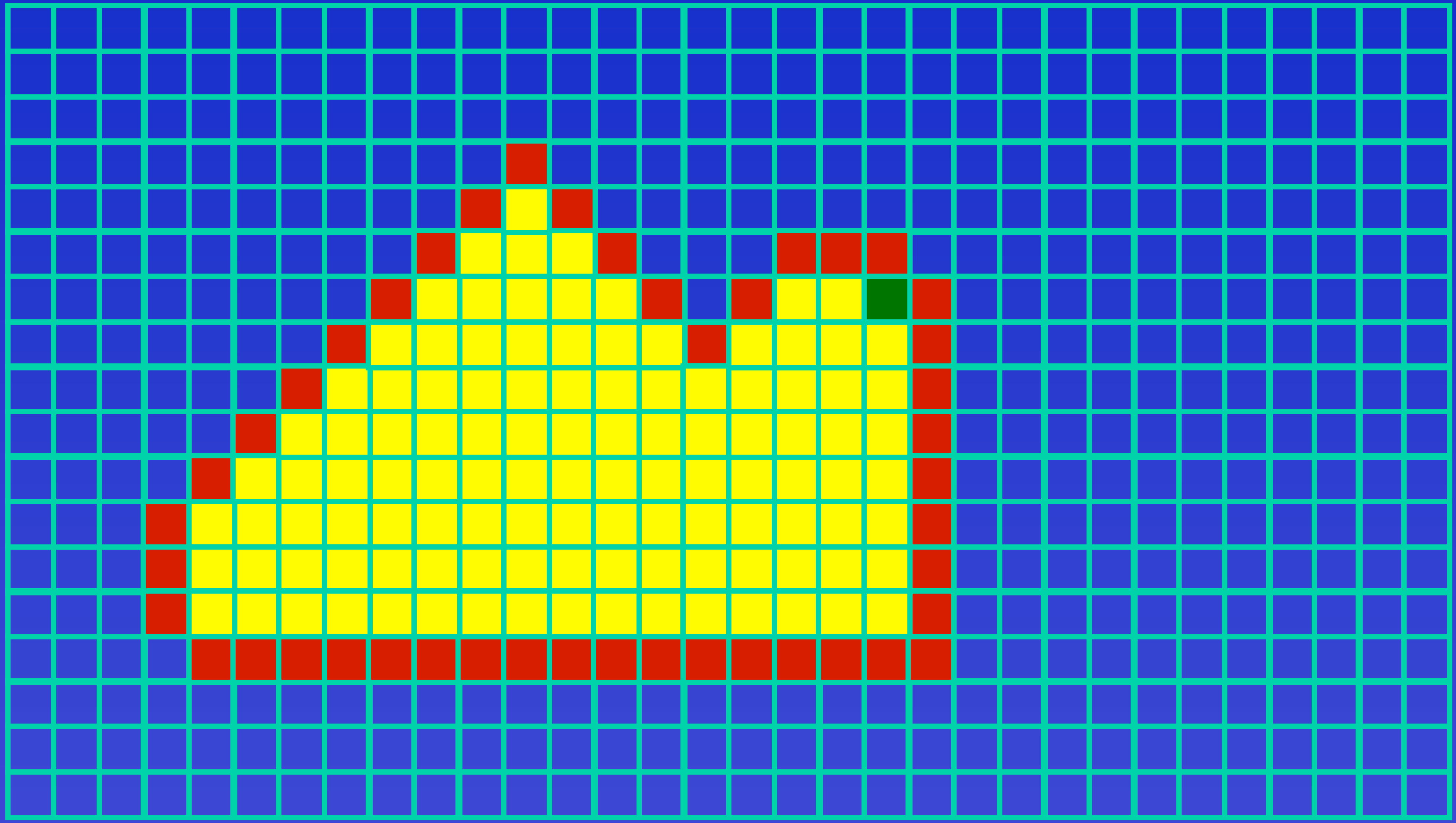
Flood Filling



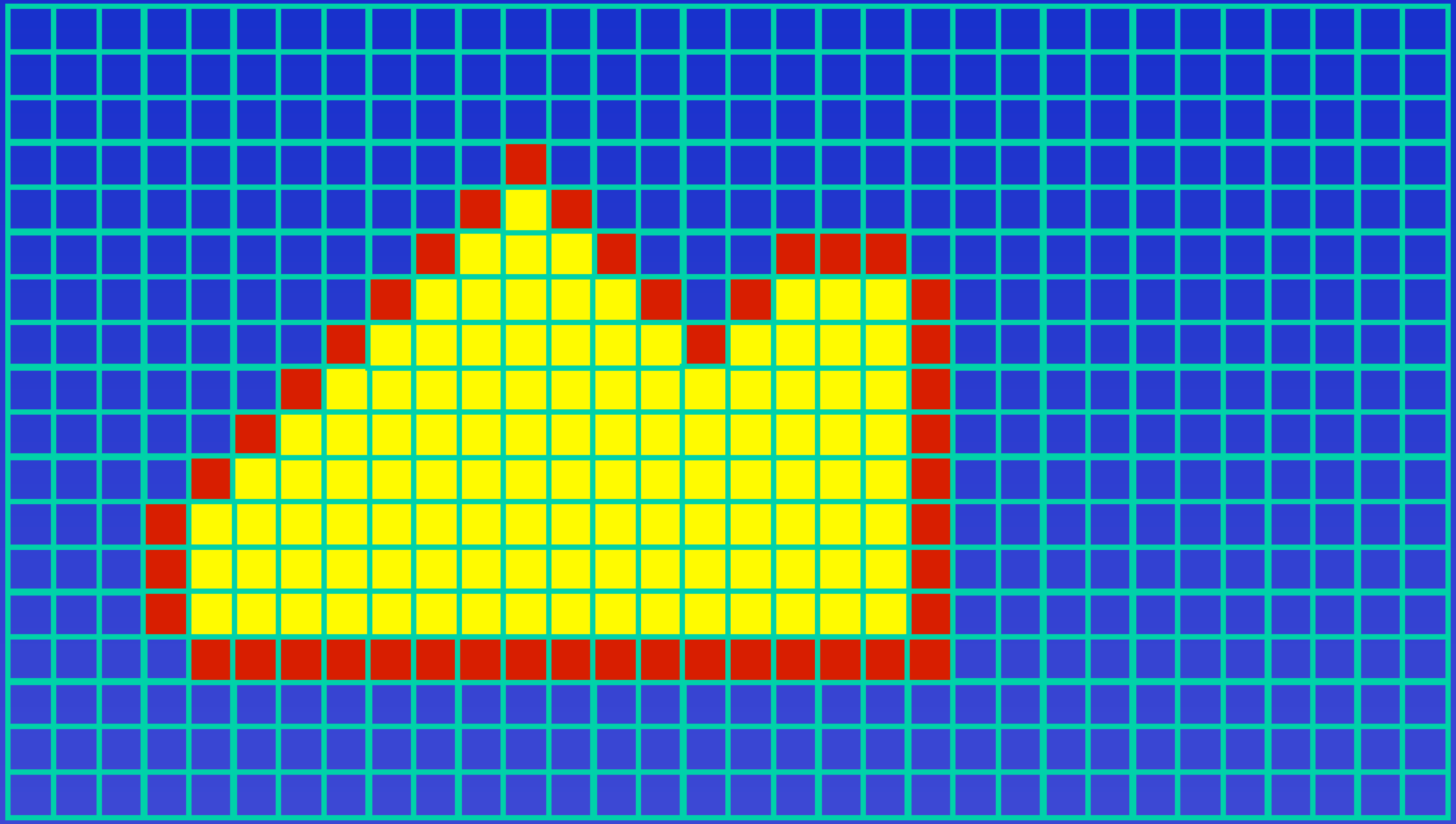
Flood Filling



Flood Filling



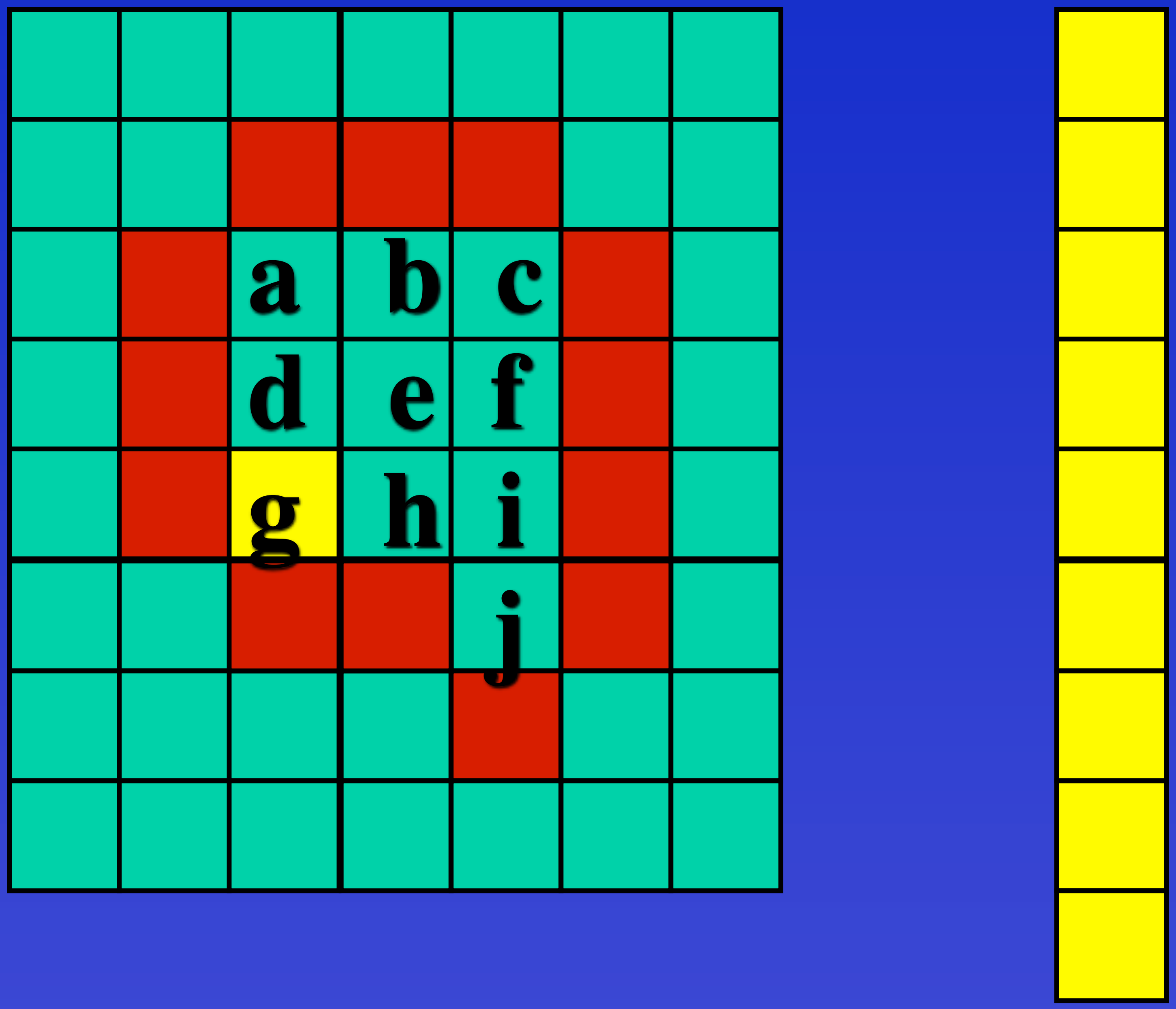
Flood Filling



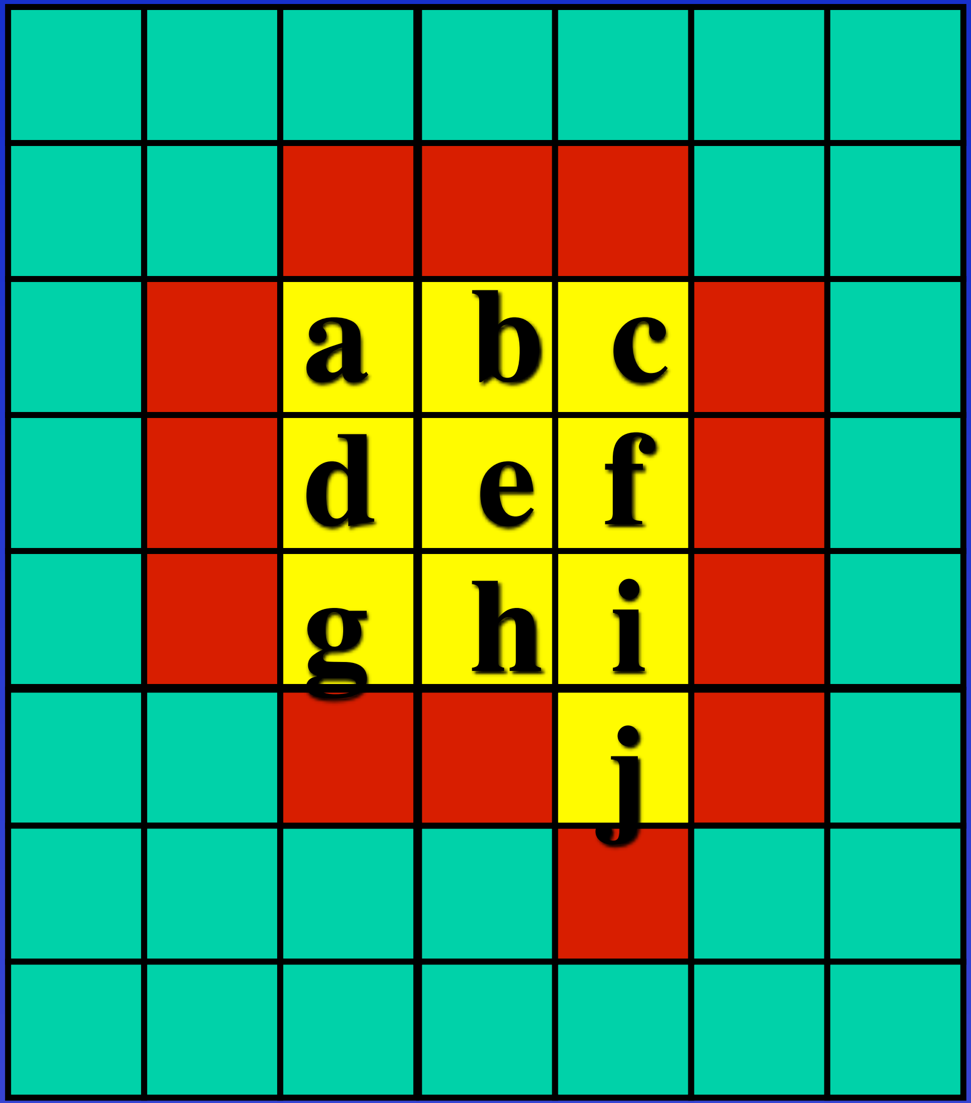
Simple approach

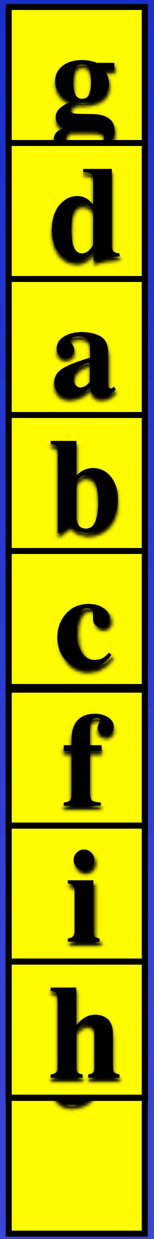
```
void fill(pixel me)
{ pixel tmp;
  colour(me);
  for(tmp = each me-neighbour)
  { if (!coloured(tmp)) then
      fill(tmp);
  }
}
```

Watch the stack

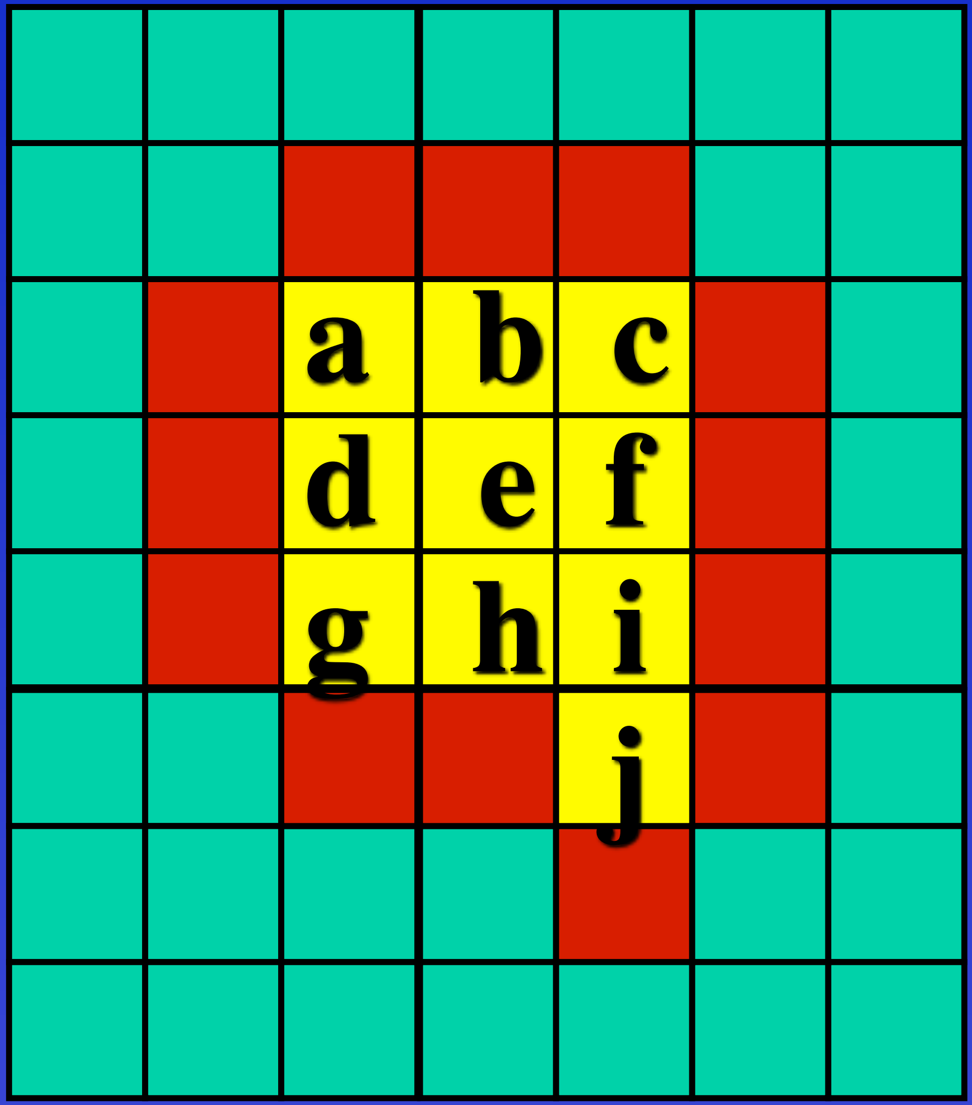


Watch the stack



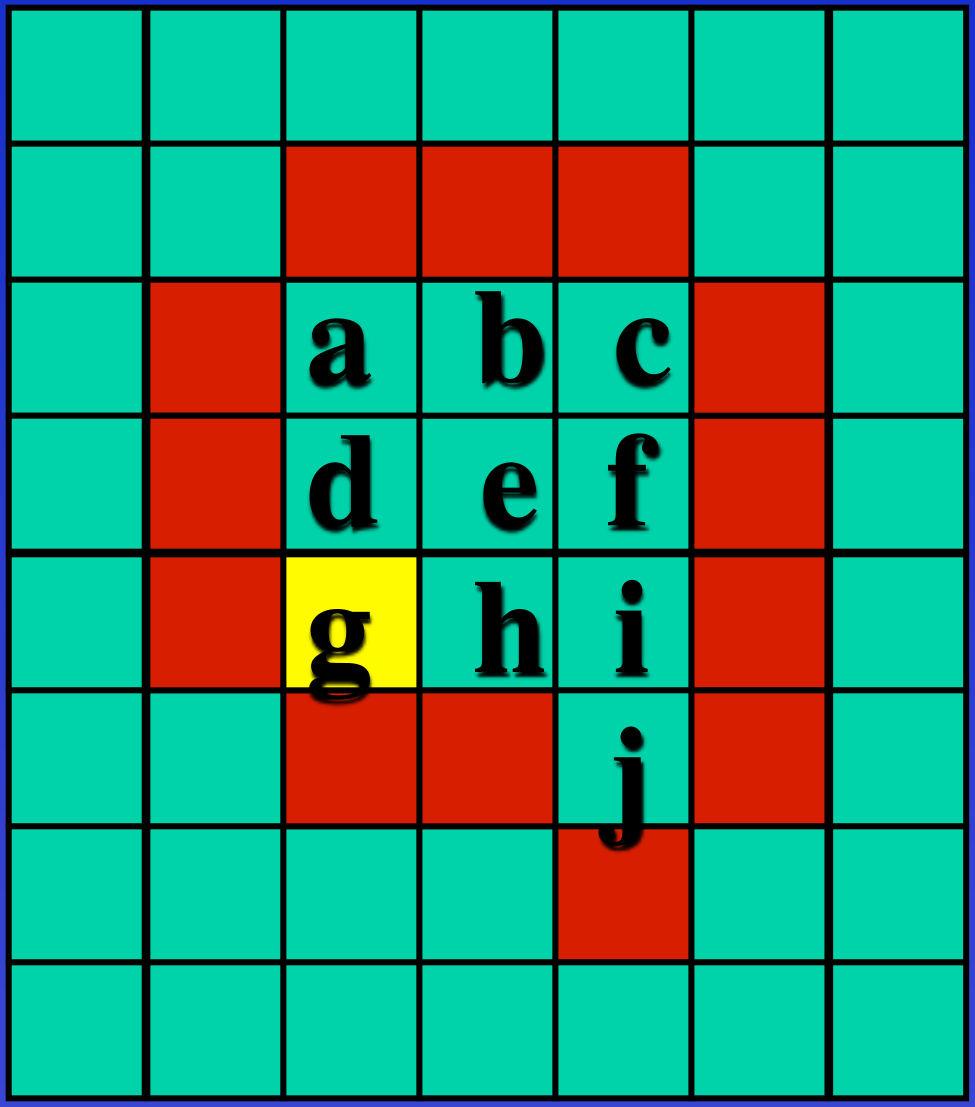


Watch the stack



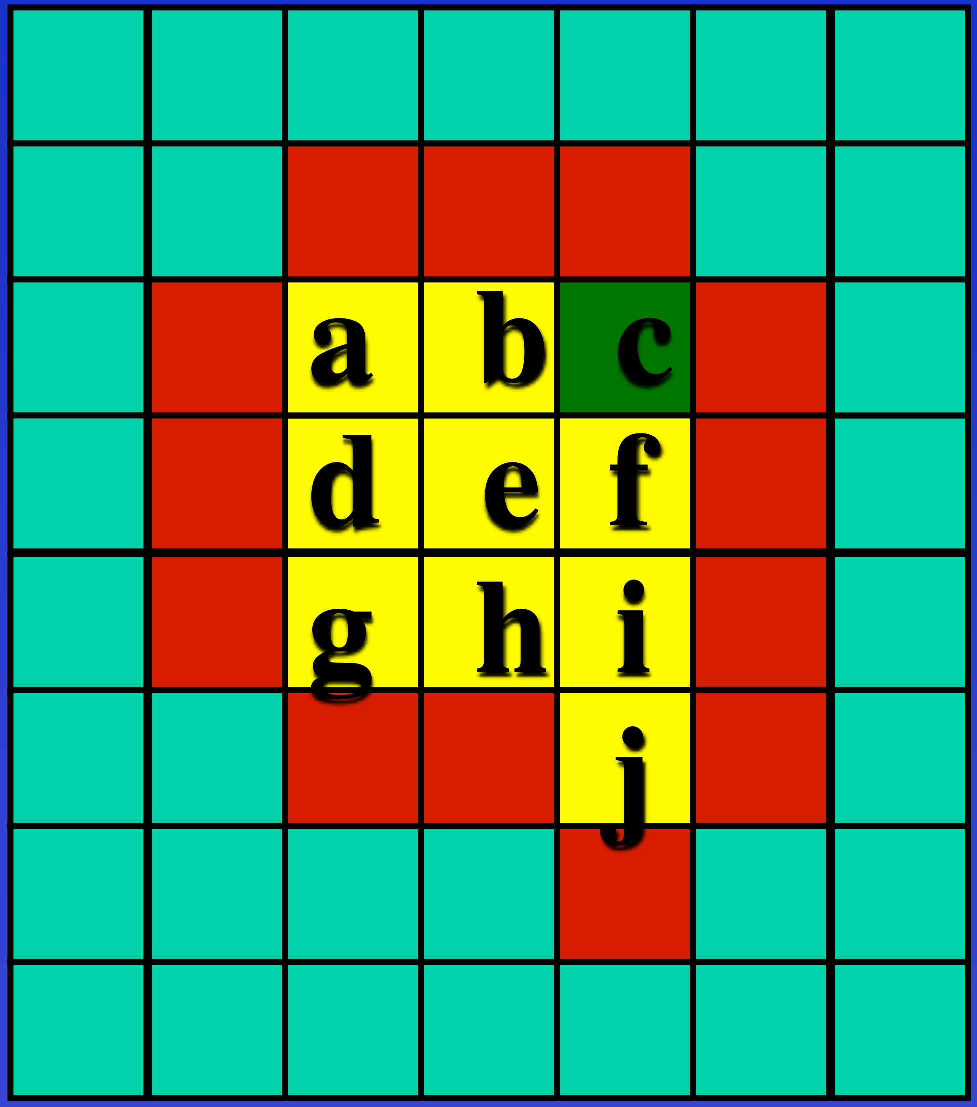
g
d
a
b
c
f
i
h
e

Better with a queue



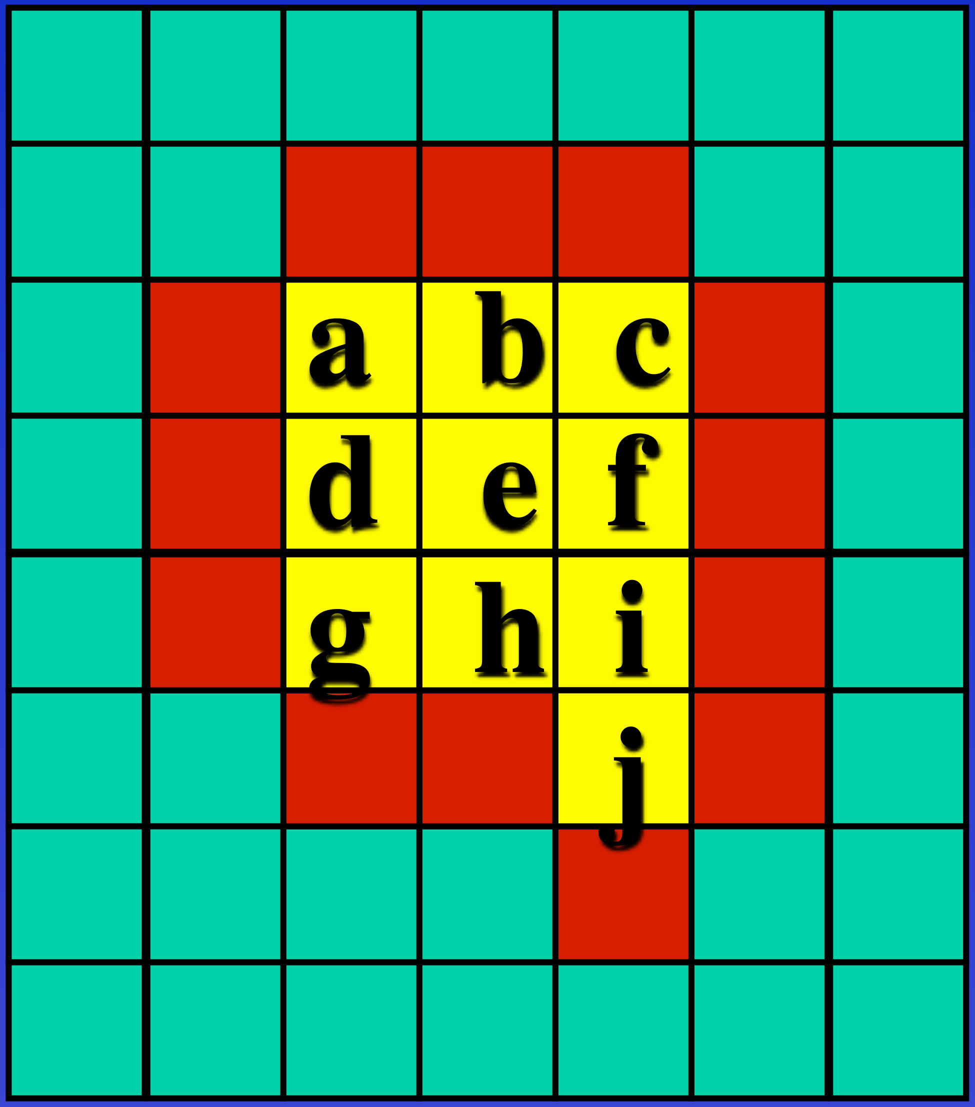
g d h a e i b f j c

Better with a queue



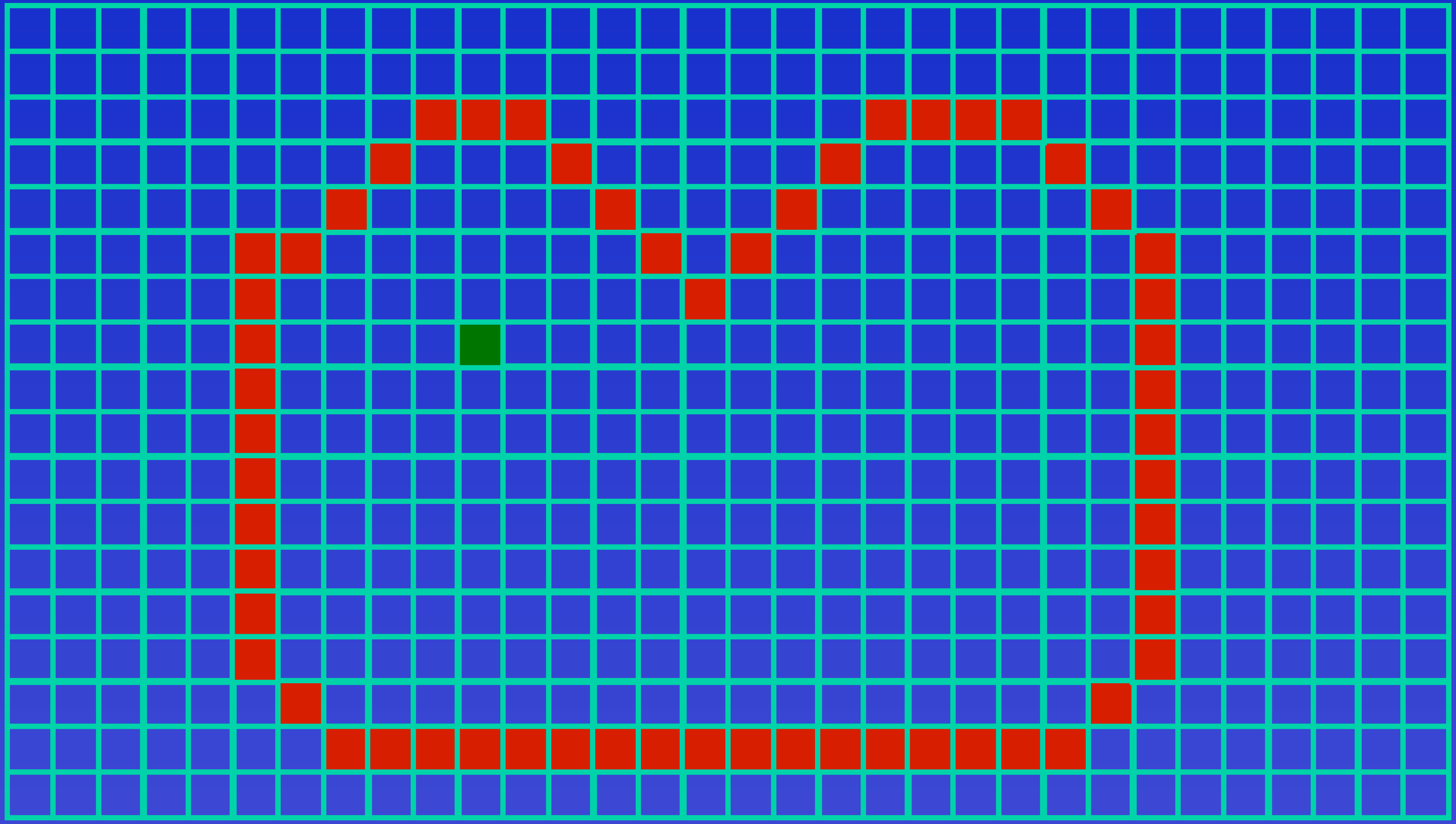
g d h a e i b f j c

Better with a queue



g d h a e i b f j c

Better yet with runs



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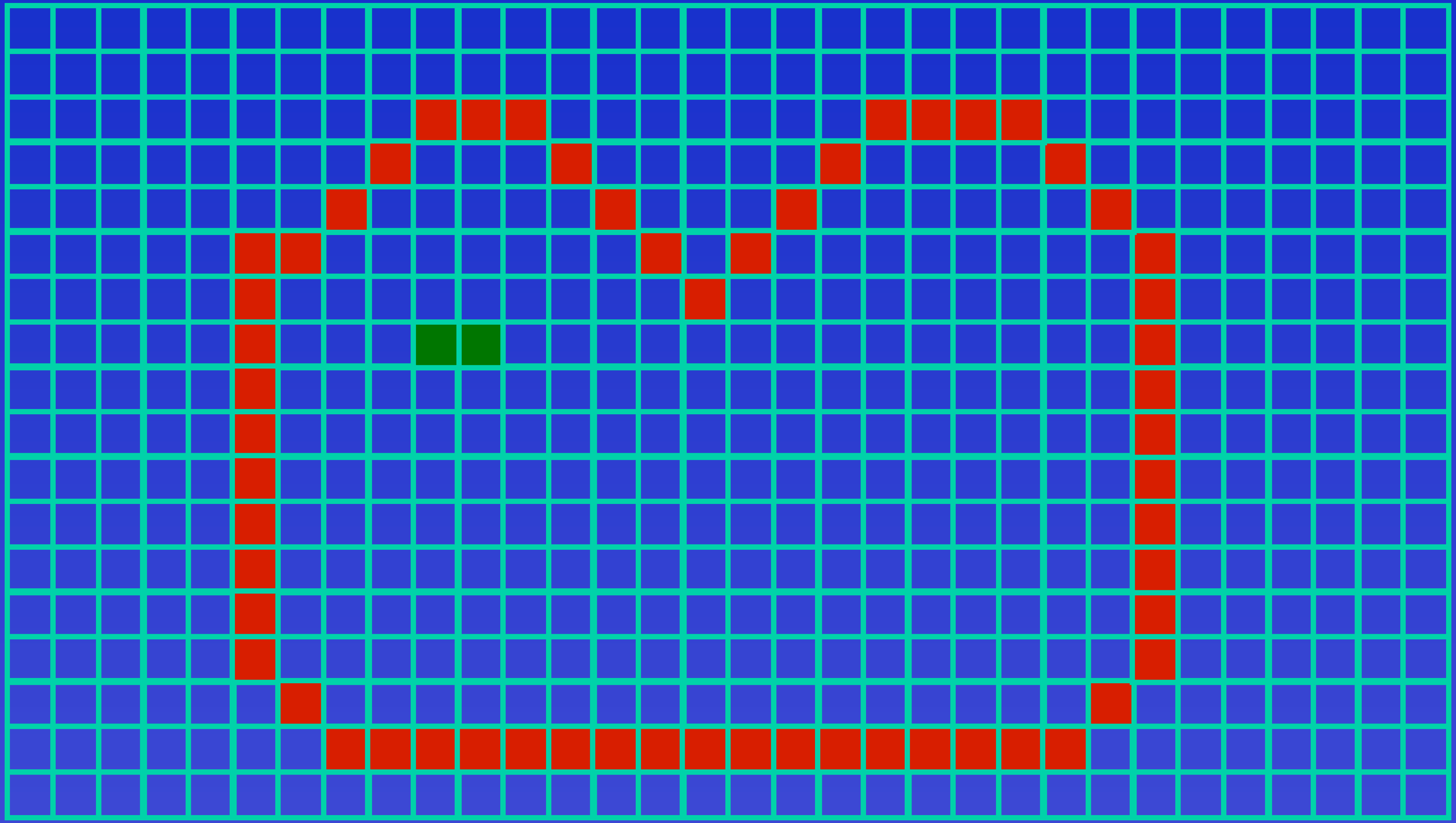

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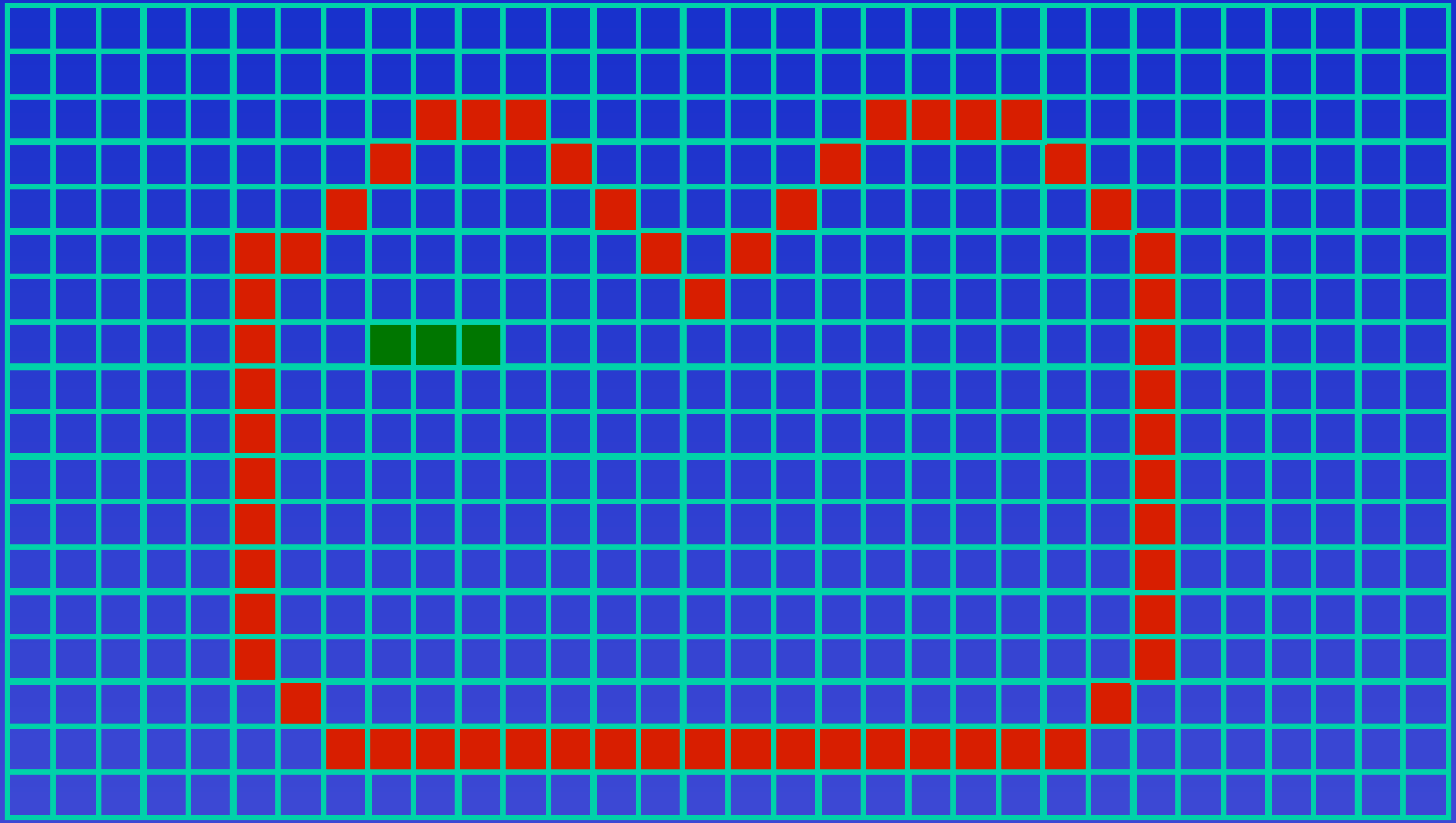

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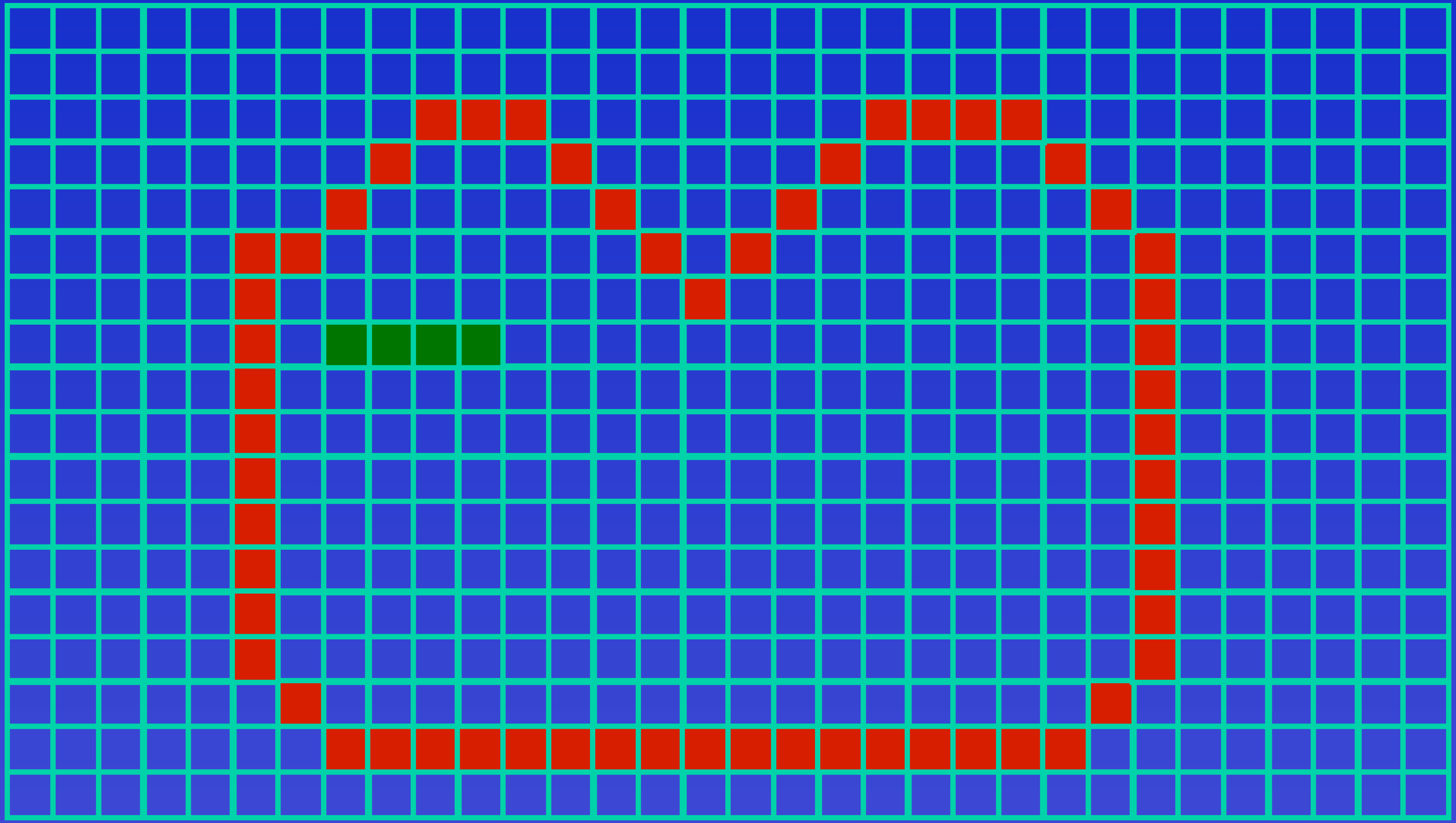

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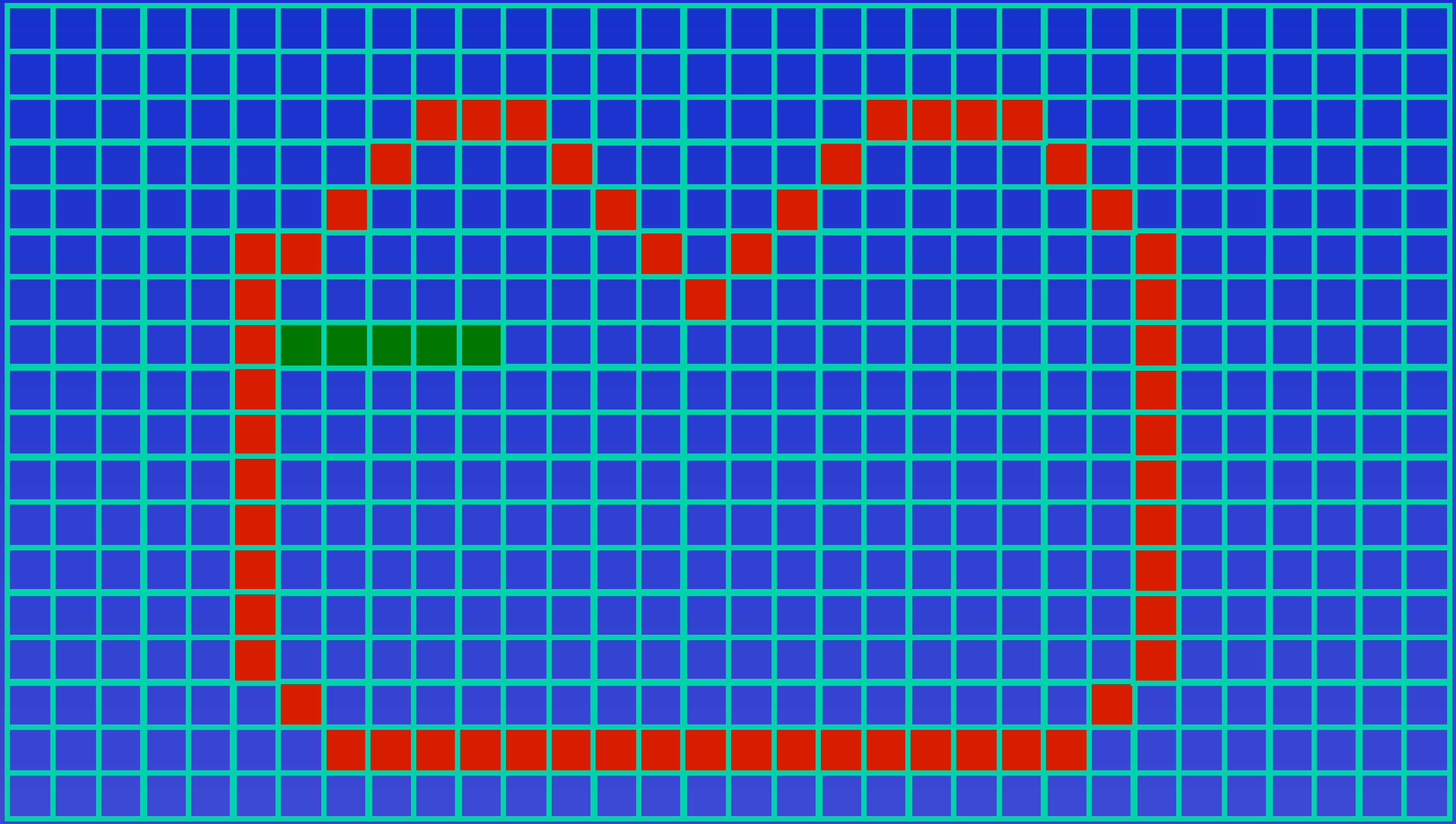
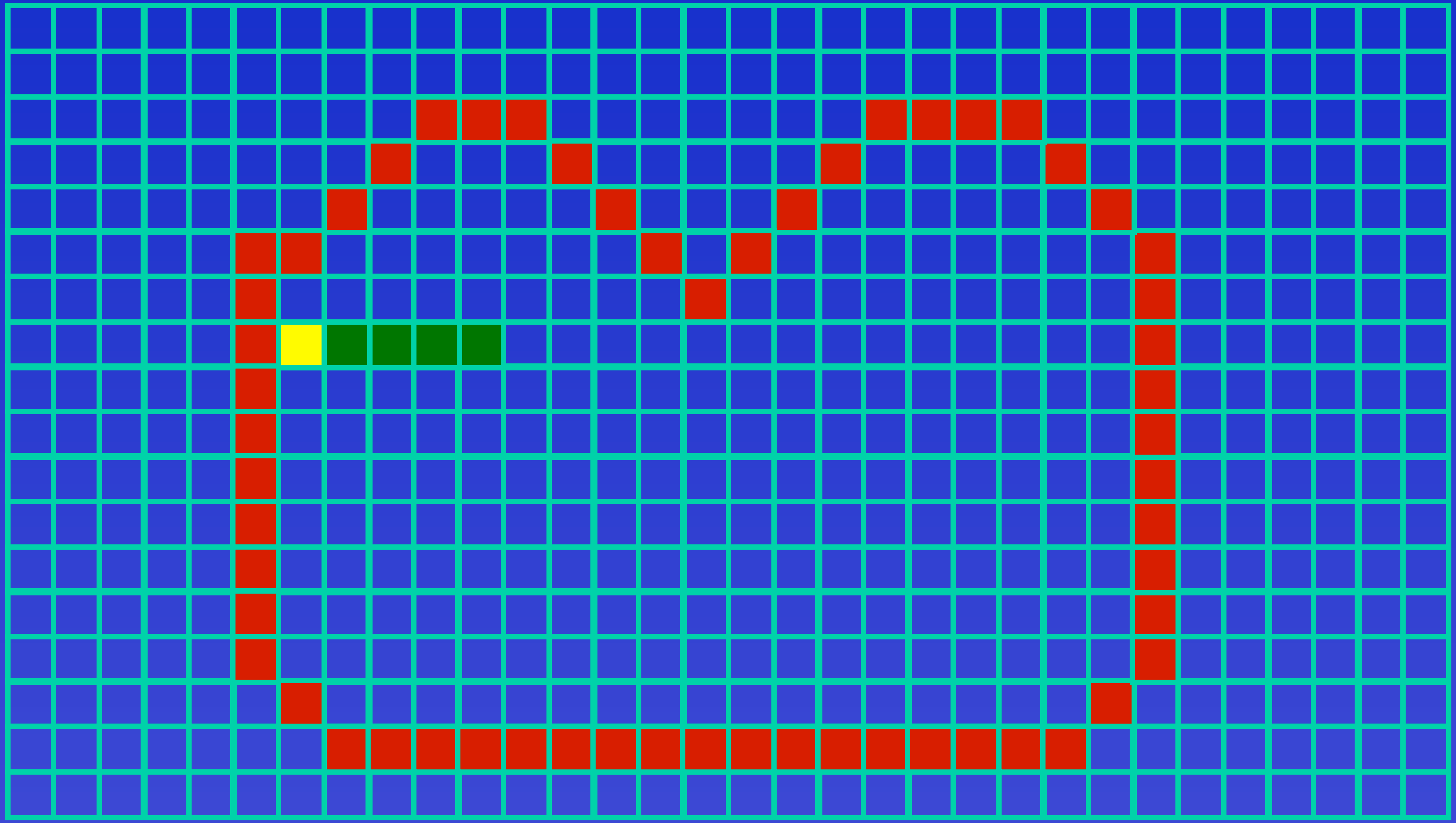
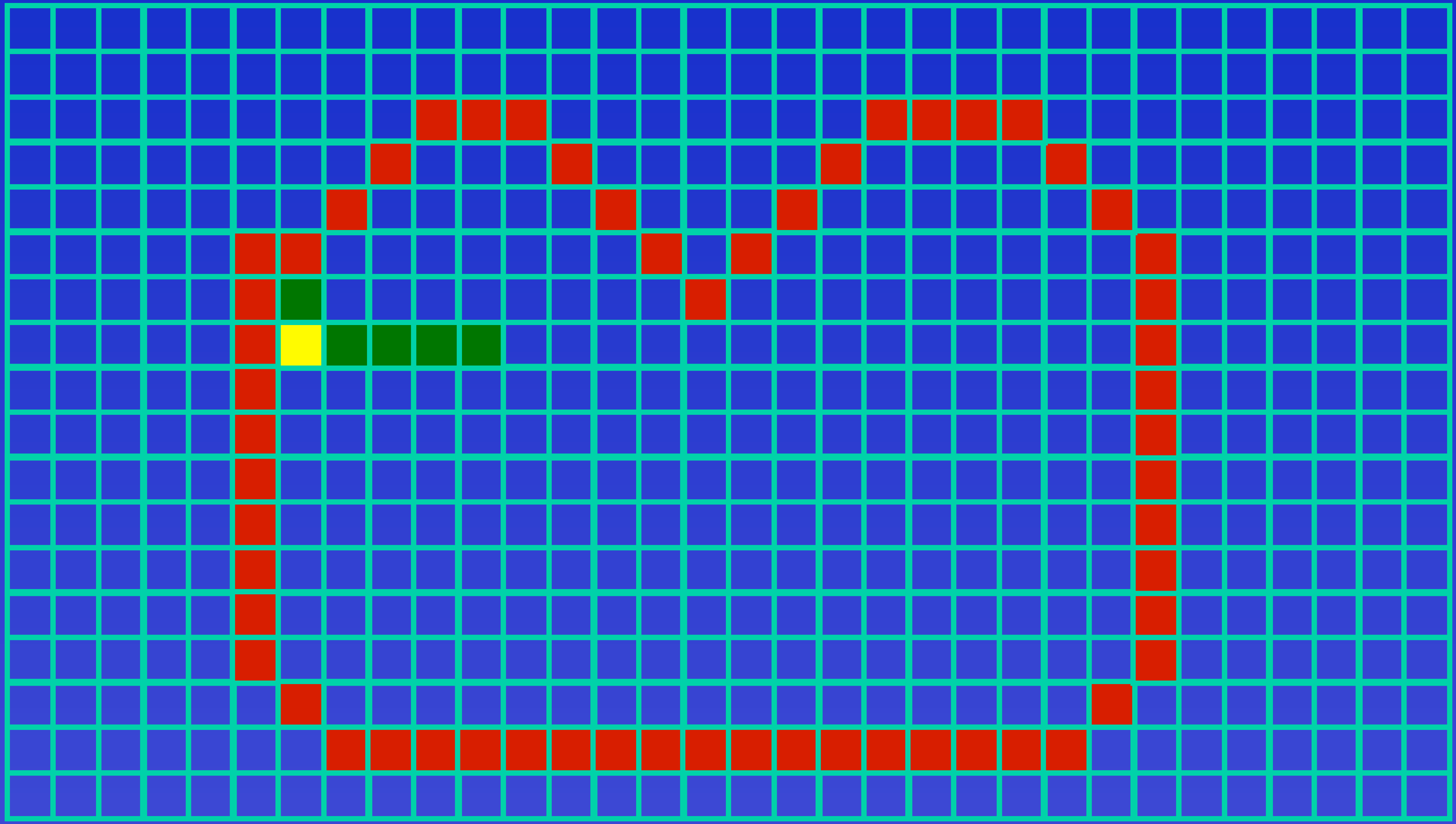


Better yet with runs



Better yet with runs



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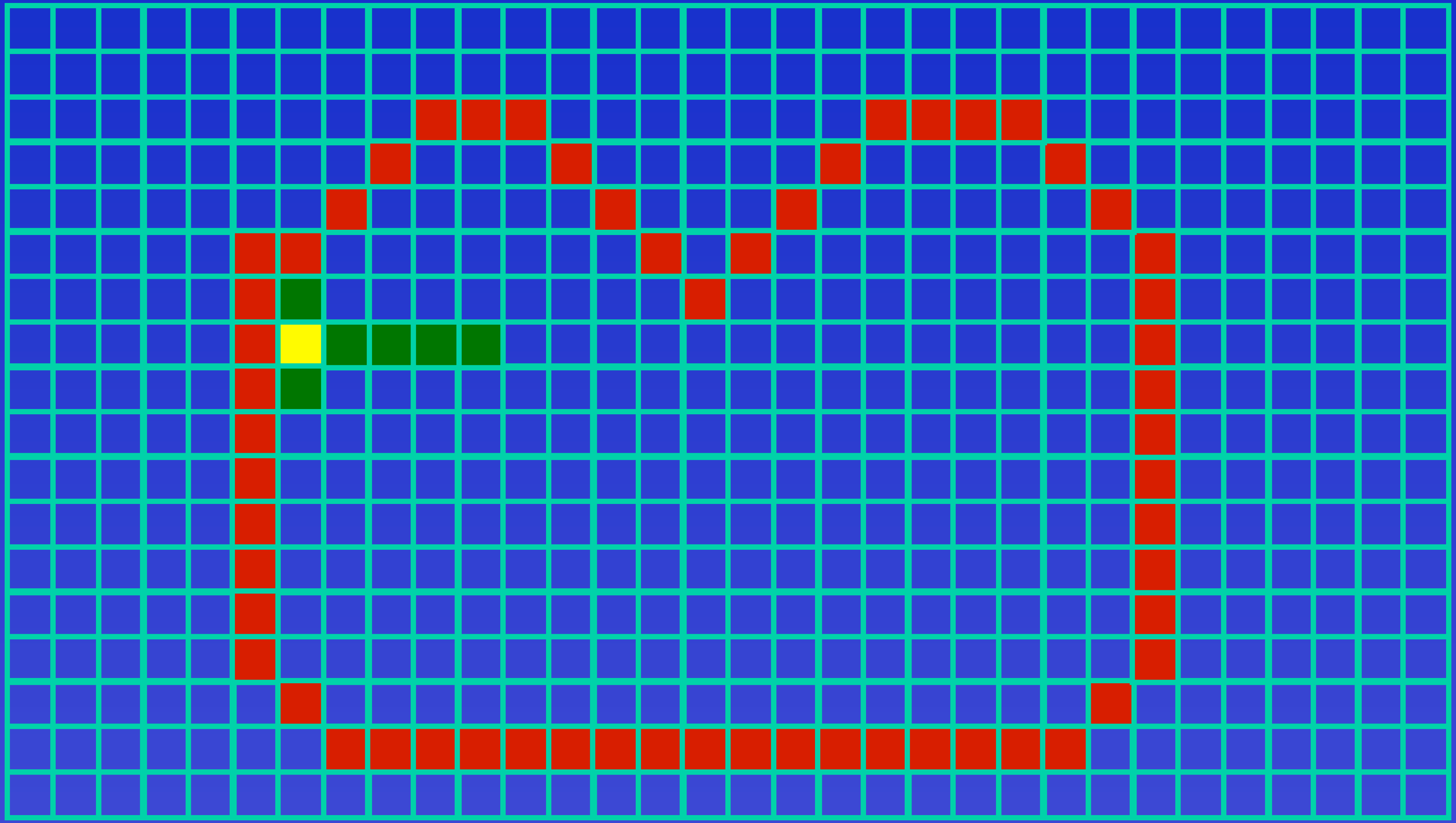

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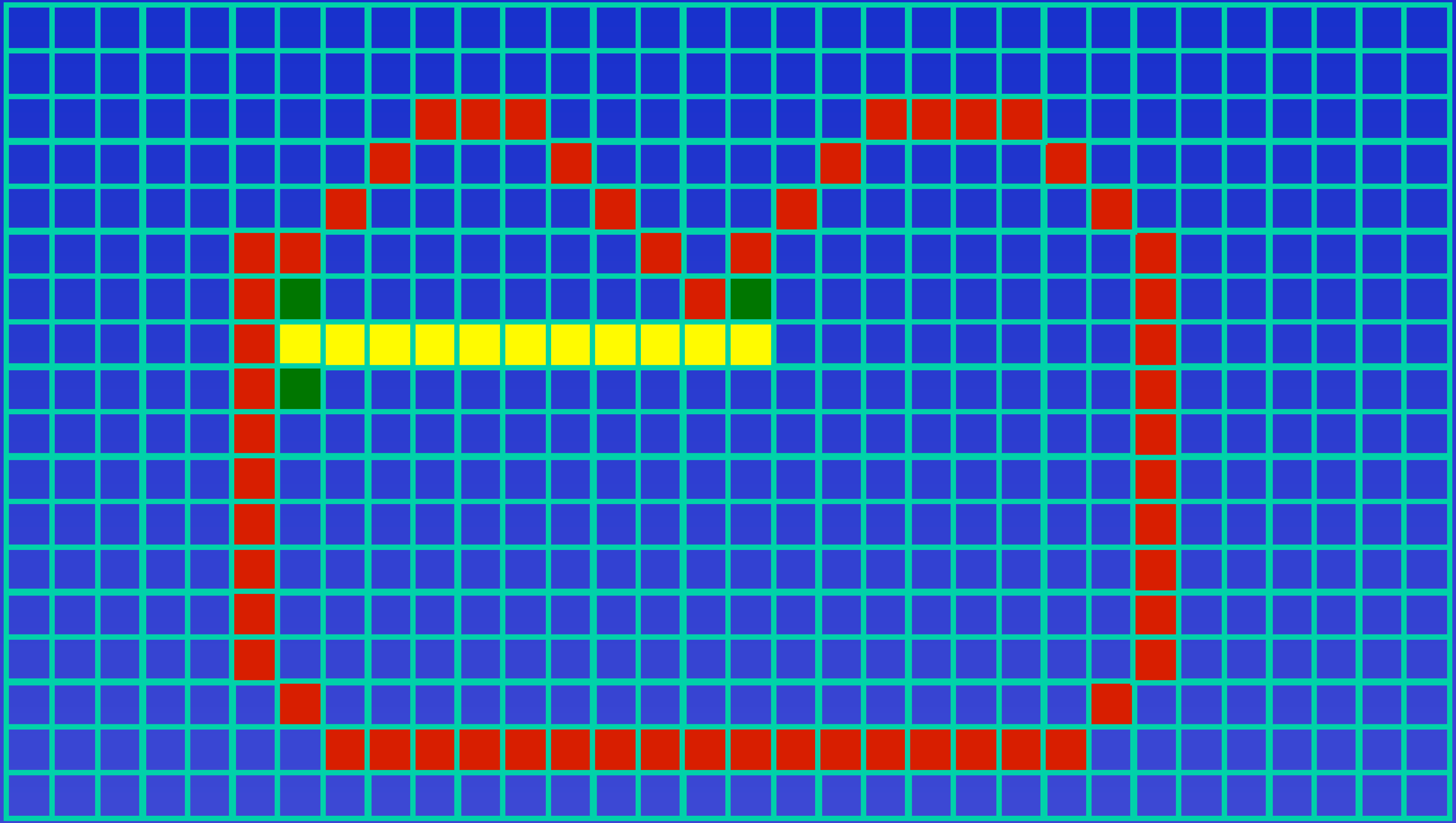

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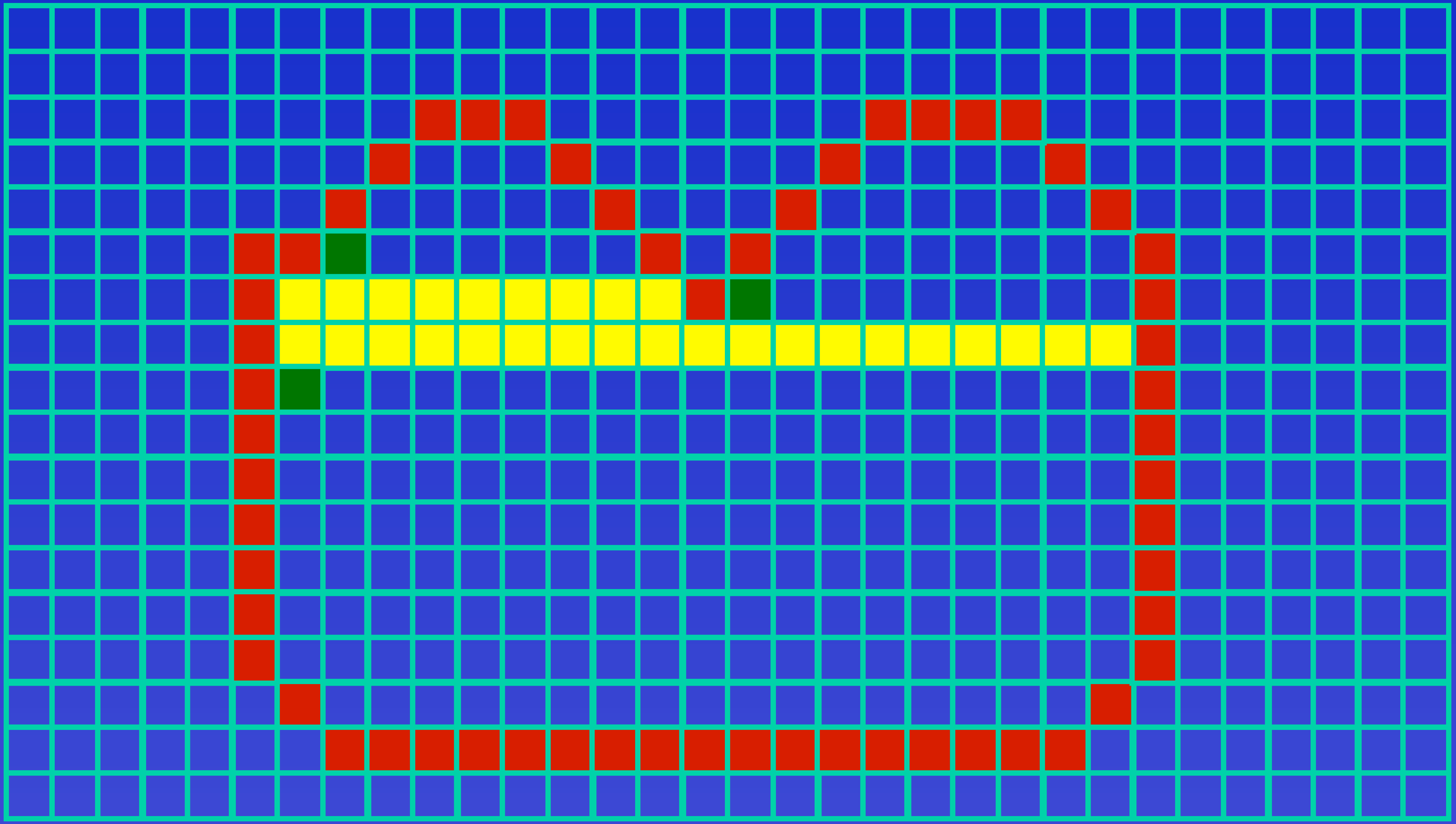
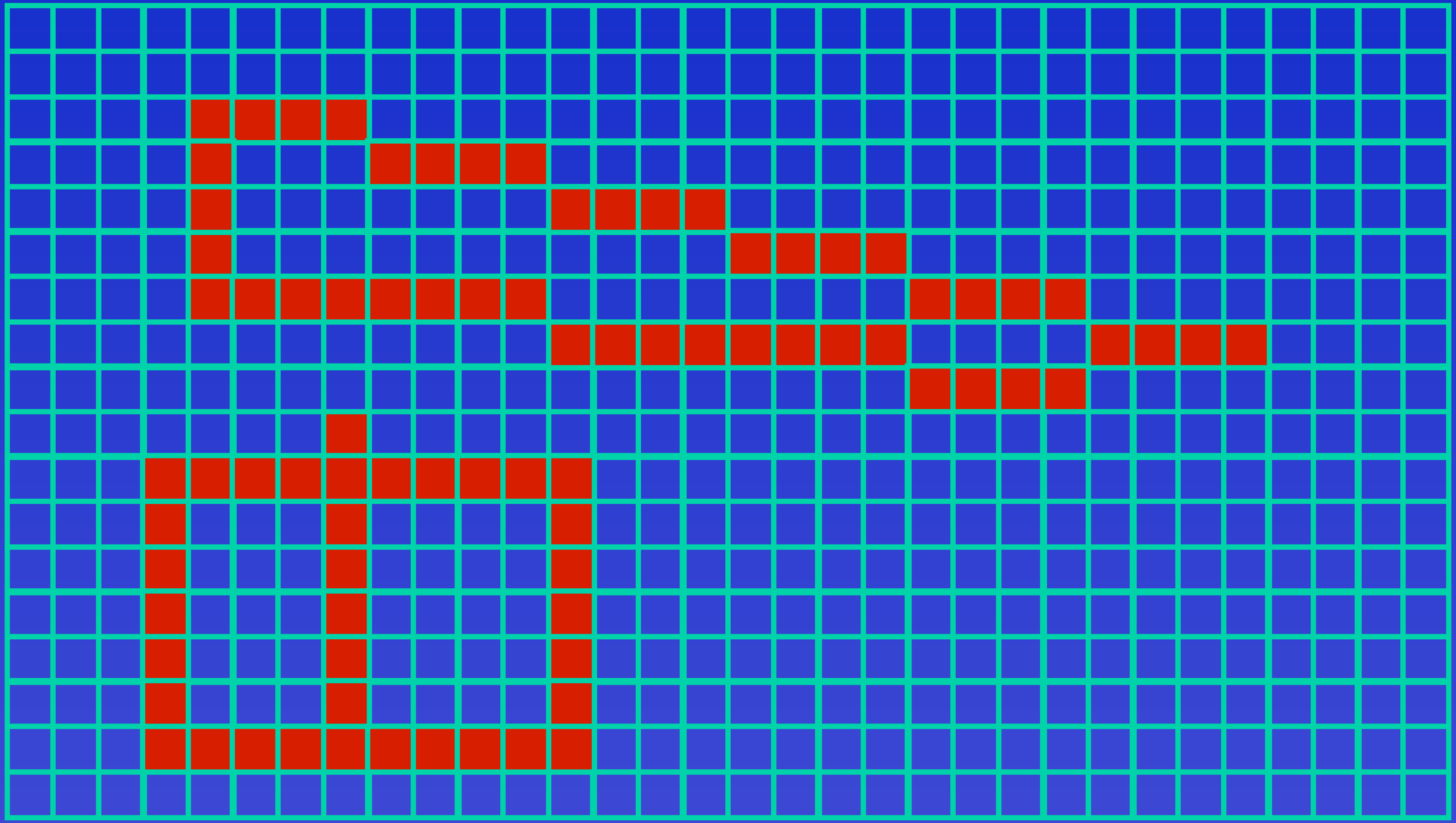
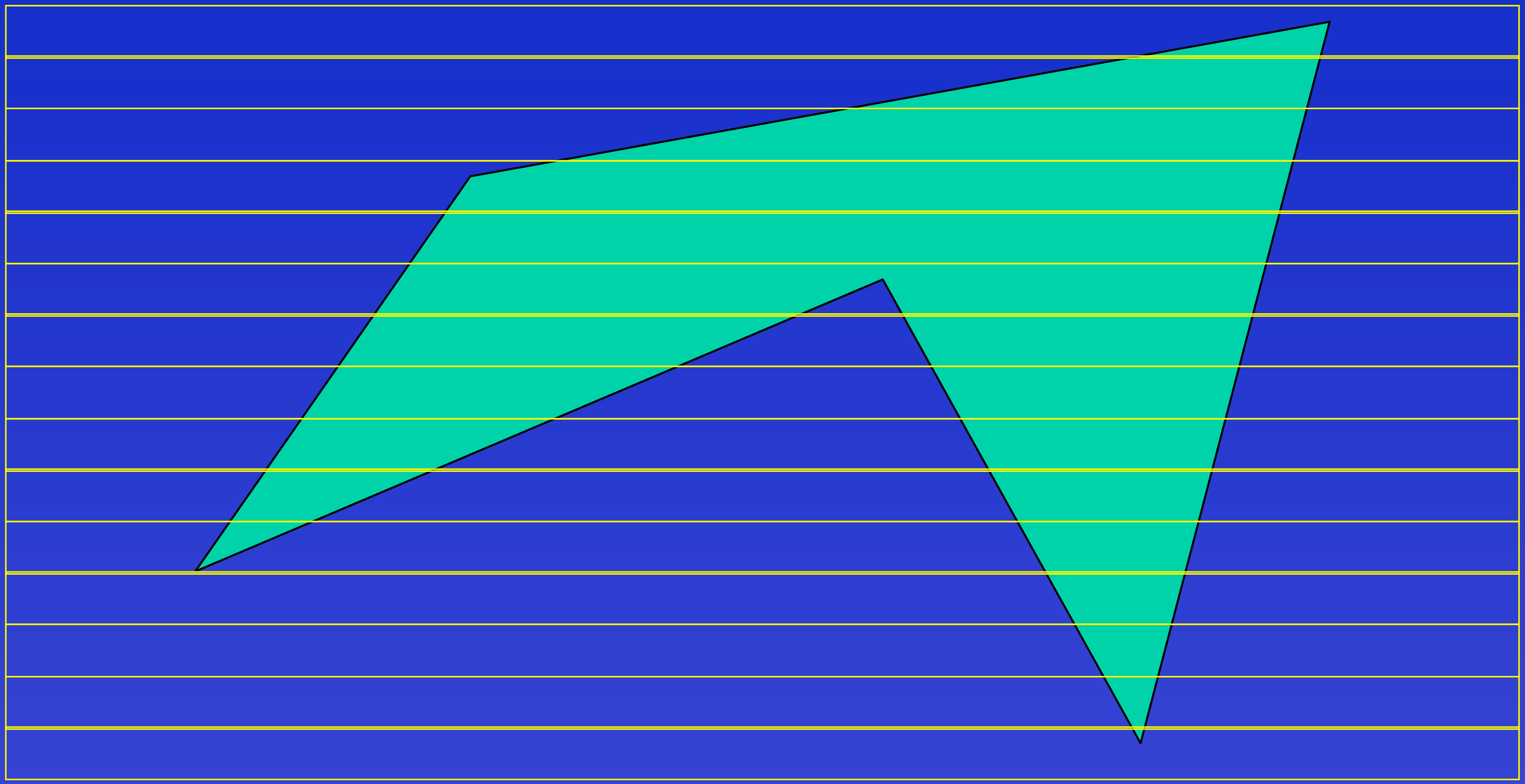


Inescapable problems

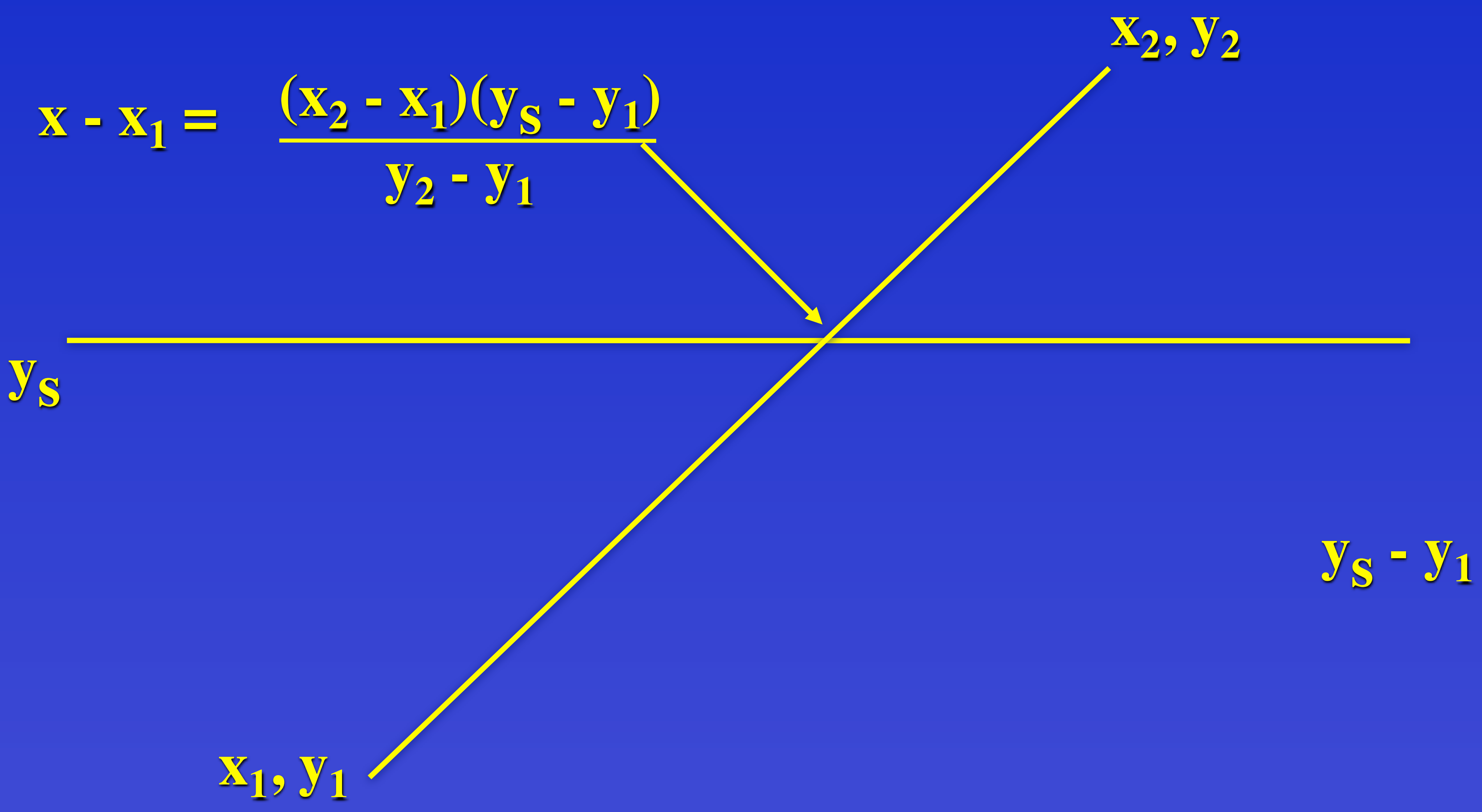


Don’t wait for pixels...



...Scan across raw polygon

Intersection calculation



$$x - x_1 = \frac{(x_2 - x_1)(y_S - y_1)}{y_2 - y_1}$$

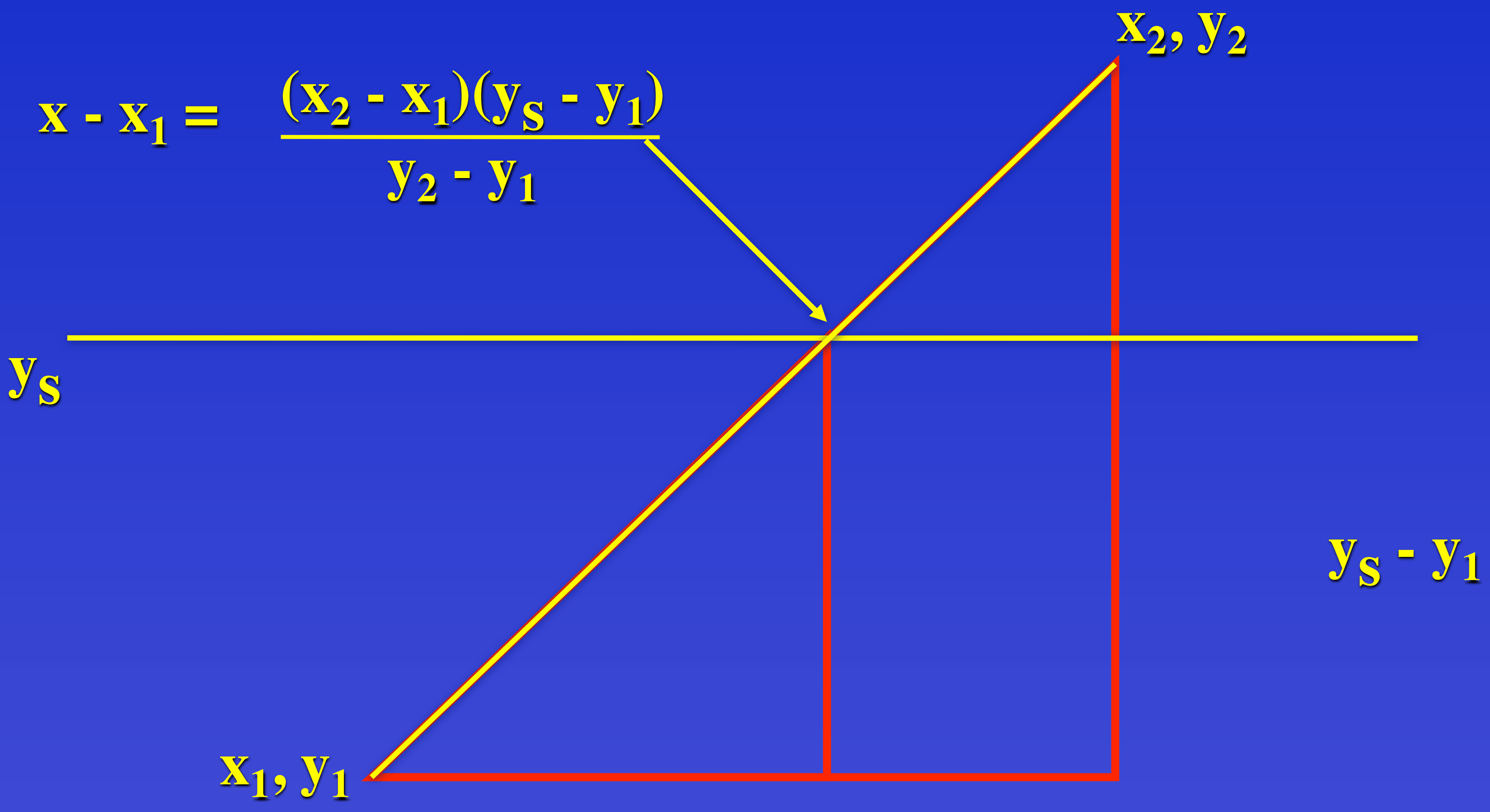
x_2, y_2

y_S

$y_S - y_1$

x_1, y_1

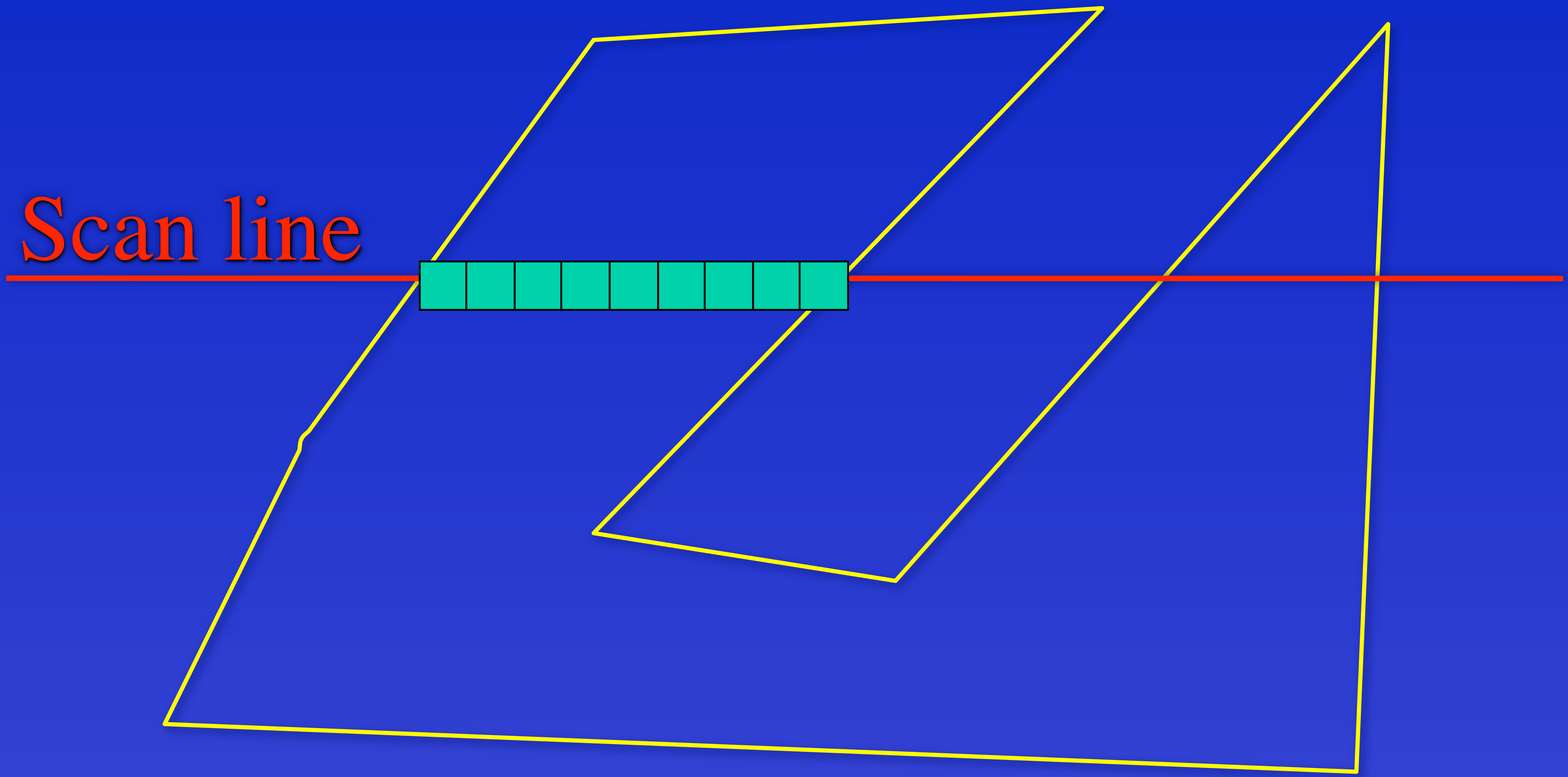
Intersection calculation

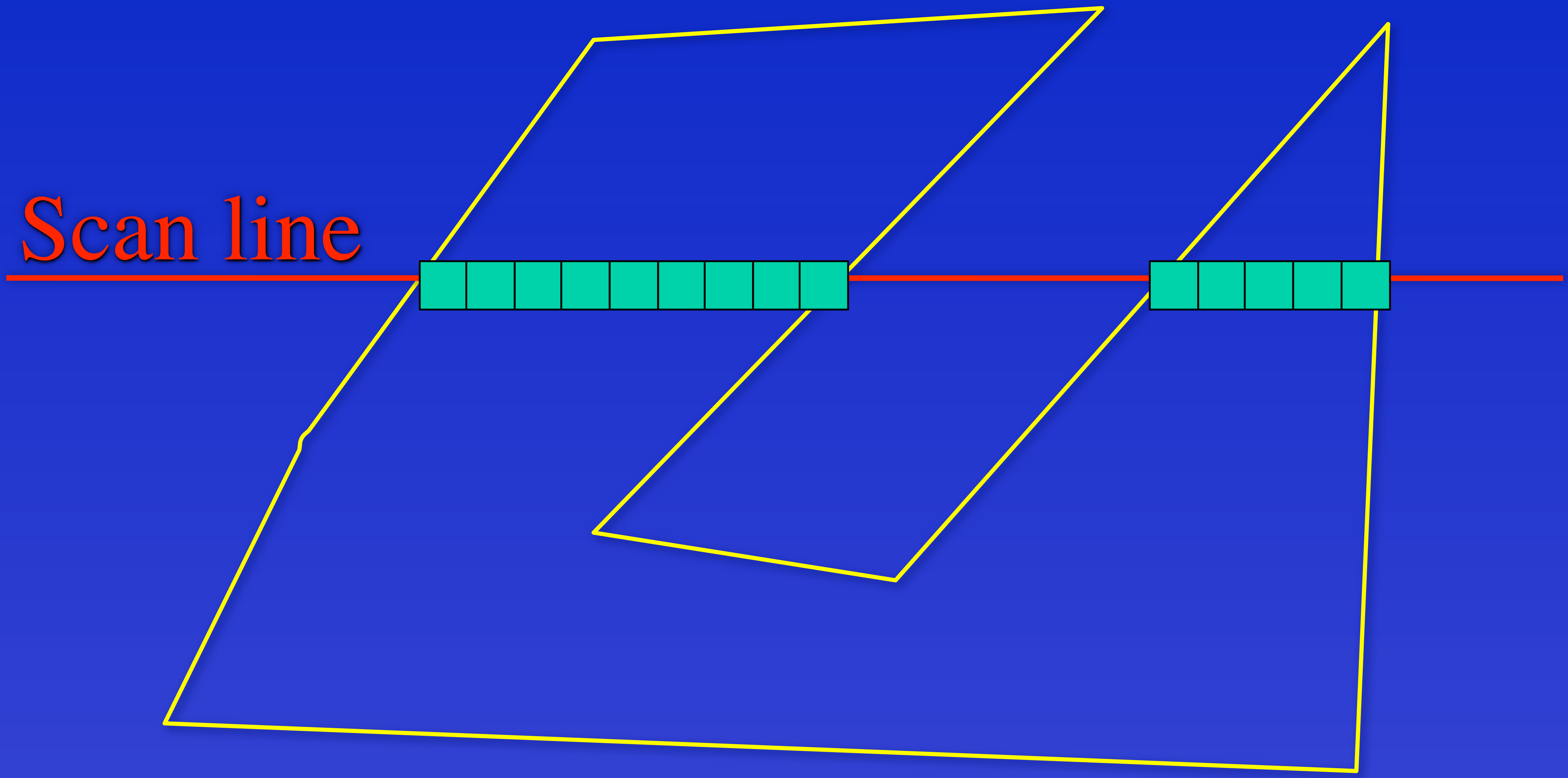


$$x - x_1 = \frac{(x_2 - x_1)(y_S - y_1)}{y_2 - y_1}$$

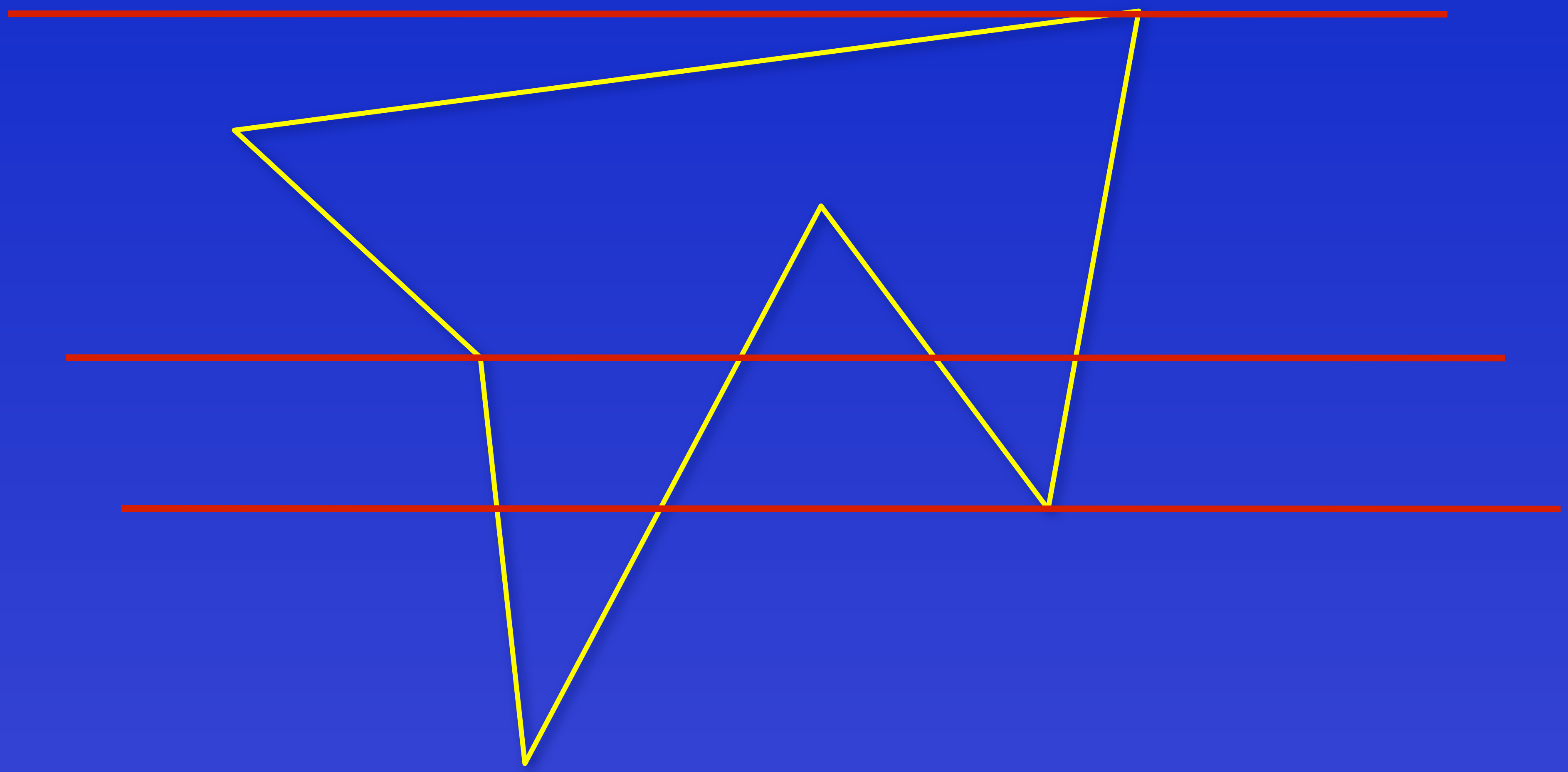
Basic scan-line filler

- Scale polygon to screen coordinates
- For each horizontal line find all intersections with polygon edges
- Draw in alternate line segments

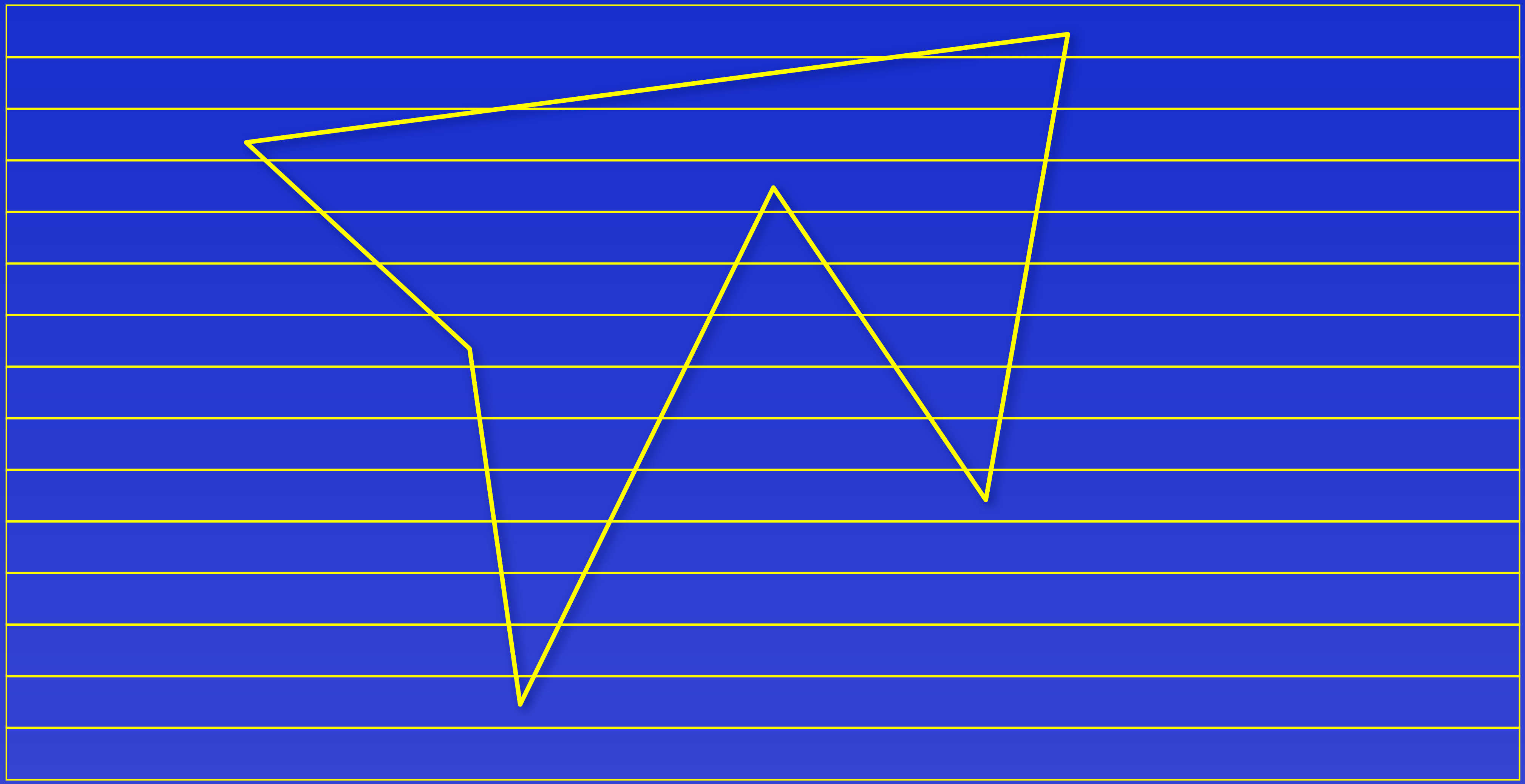

Scan line


Scan line

Double intersection



Offset vertices



Aha!