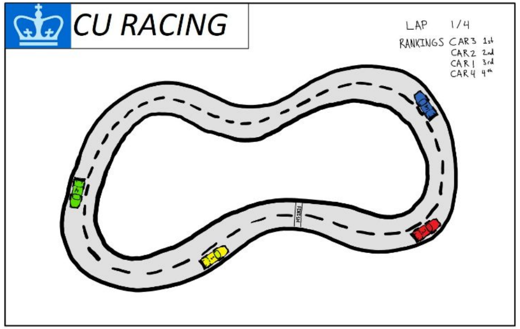
CU RACING

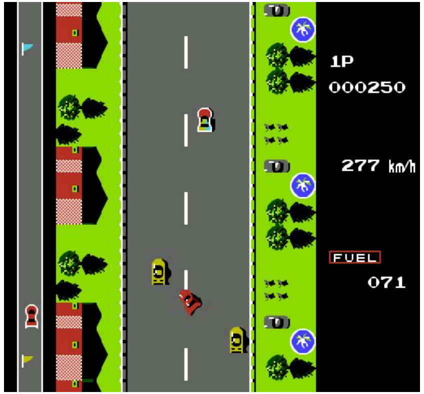
Blayne Kettlewell
Raghavendra Sirigeri
Shikhar Kwatra
Chandan Kanungo

Project Concept Evolution

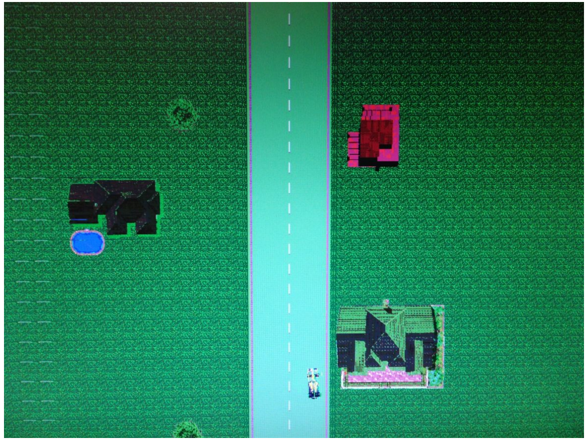
Early Concept



Precedent Ideas



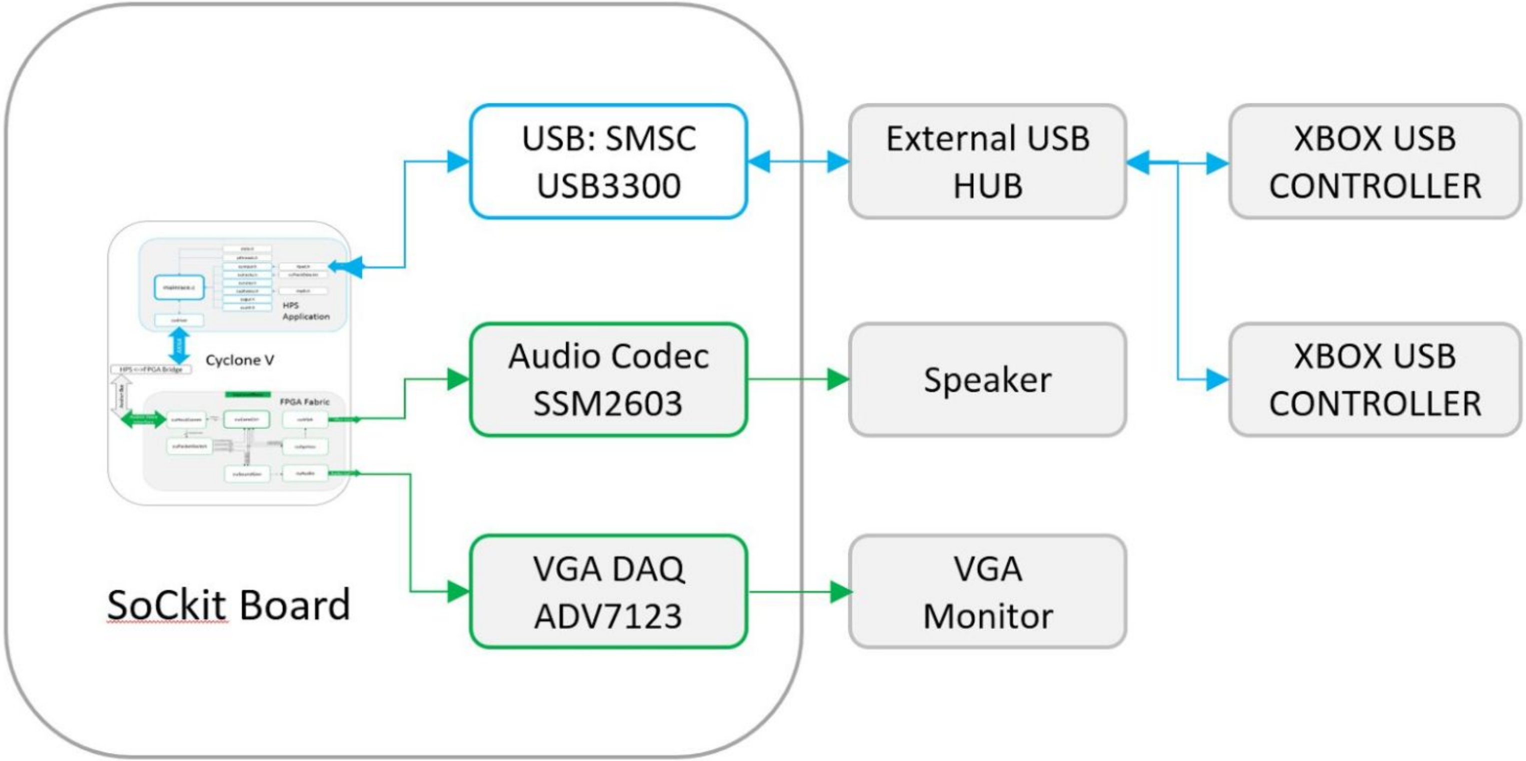
Final Gameplay



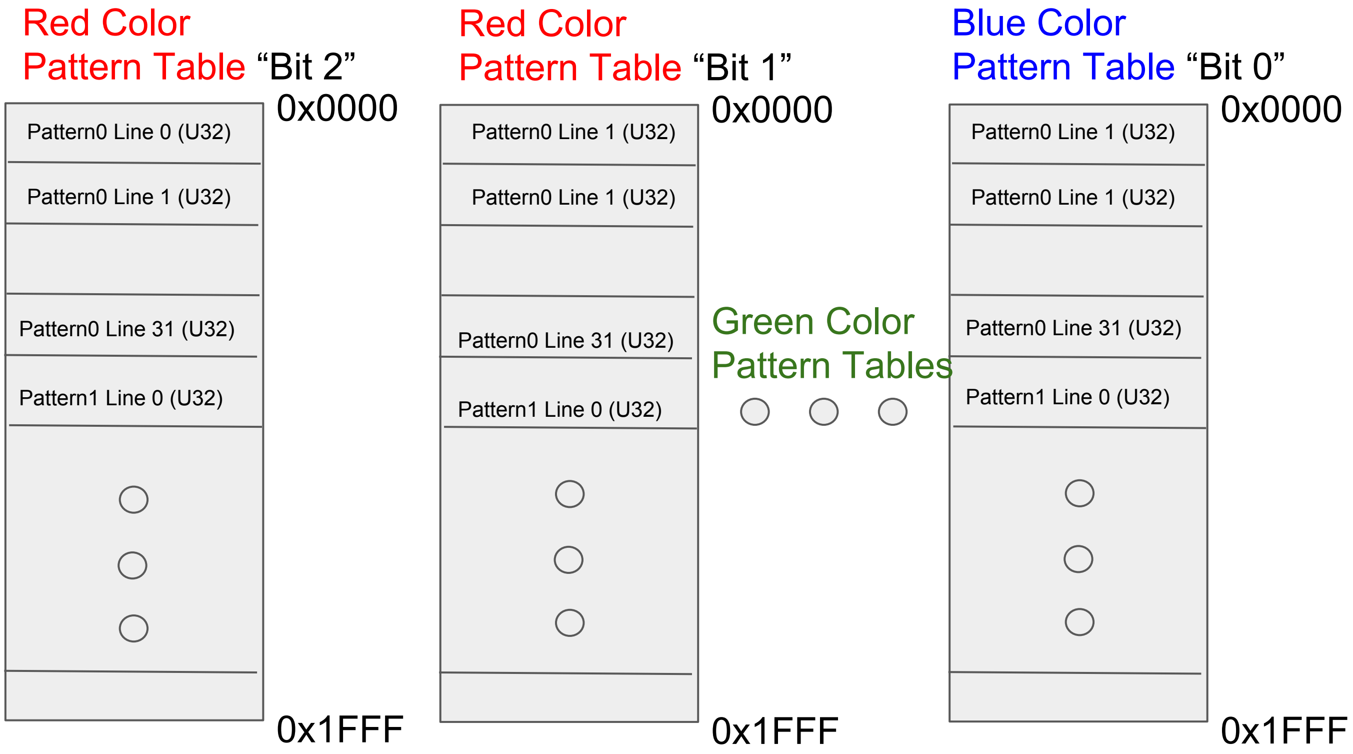
Project Goals

- Design a Sprites Graphics engine inspired from the TI TMS9918
  - Extend texture resolution from 8 pixels to **32 pixels, sprite resolution >= 64 pixels**
  - Update colors from Light/Dark pixels to **9 bit colorspace** (512 color alternatives/pixel)
- Enable screen scrolling in all directions
- Runtime image programming interface for background patterns
  - No Graphics MIFs!
  - Allows for simplified creation of new game tracks and menus
  - Mitigates limited RAM space on the Cyclone V
- Update VGA resolution to XGA (1024 x 768 60 Hz)
- Implement real-time computation of sprite rotation
- Enable game sounds
- Model car physics and have realistic race dynamics

CU Racing HW Interface Diagram

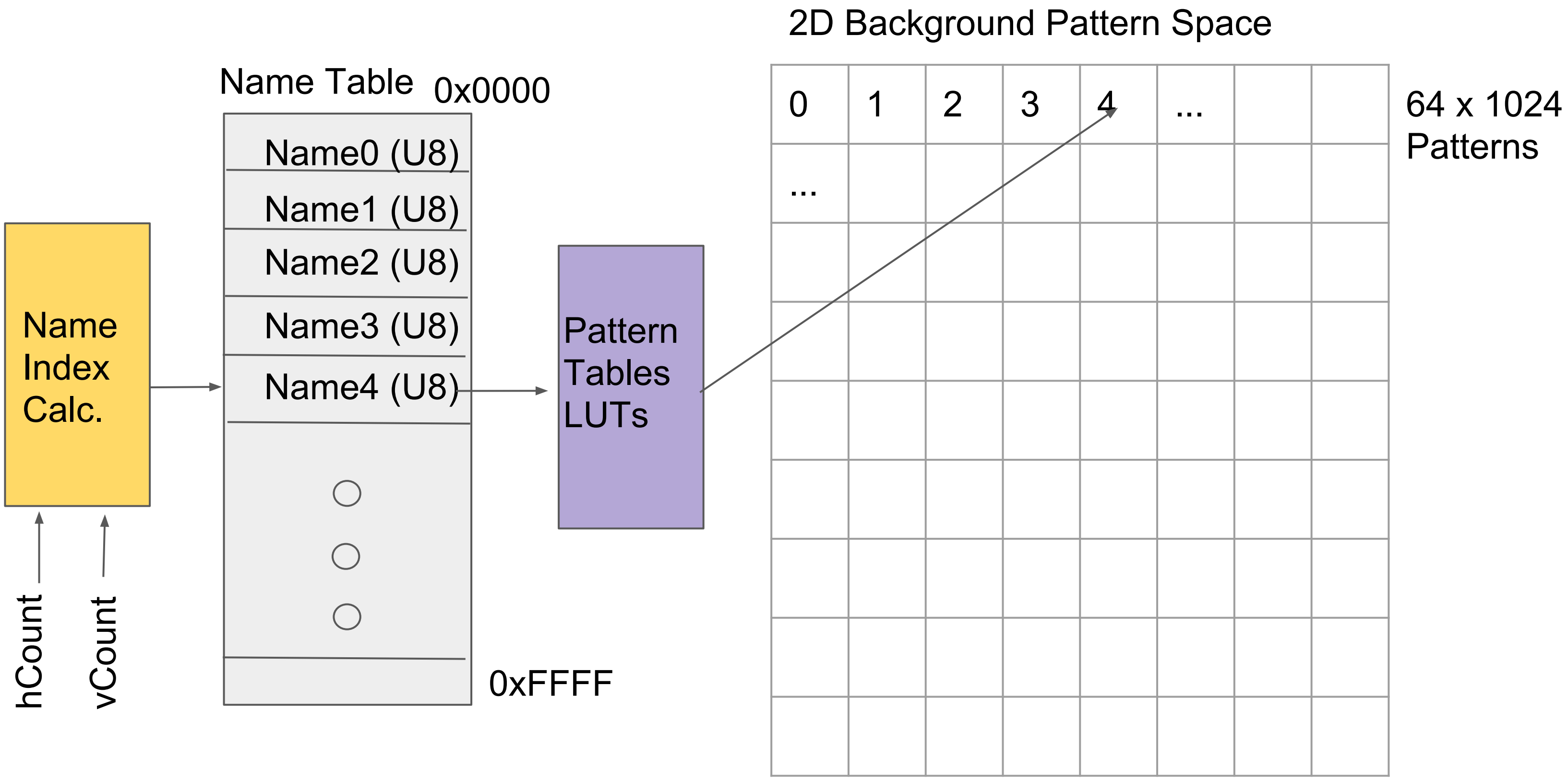


Sprite Graphics Implementation - Pattern Tables

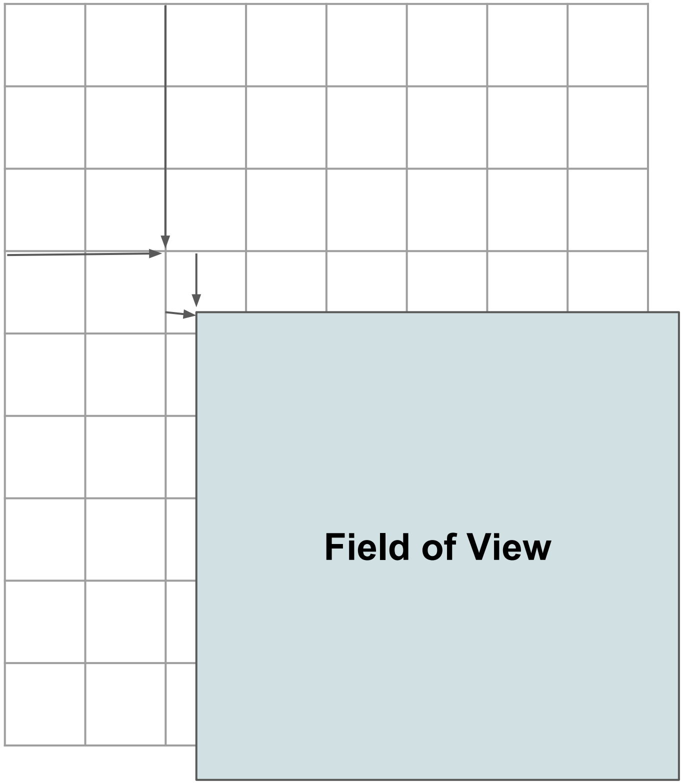


- 9 Independent Dua
  Port RAMs to represent 512 colors/pixel
- Large "register address space"
- 8192 32 bit words /
  (32 bits/ pattern)
  - 256 patterns

Sprite Graphics Implementation - Pattern Lookup



Sprite Graphics Implementation - Movement



- Coarse and fine grain movement
  - 32 pixels “nameOffsetX/Y”
  - 1 pixel “pixelOffsetX/Y”
- Updated synced to VSYNC of VGA
- Unsigned offsets were a non-ideal design choice
  - Made movement more complicated than necessary
- Reasonably smooth movement, still isolating a few bugs

Programmatic Map Generation

```
treeRowsTop = range(0,1024, 16)
treeRowsBottom = range(1,1025, 16)

houseRowsZero  = range(0,1024, 24)
houseRowsOne   = range(1,1025, 24)
houseRowsTwo   = range(2,1026, 24)
houseRowsThree = range(3,1027, 24)

for row in range(0,1024):
  for col in range(0,64):
    if (col == 29):
        print 1
    elif (col == 30 or col == 32):
        print 2
    elif (col == 31):
        print 3
    elif (col == 33):
        print 4
    # Trees
    elif (col == 26 and row in treeRowsBottom):
        print 6
    elif (col == 27 and row in  treeRowsBottom):
        print 8
    elif(col == 26 and row in treeRowsTop):
        print 5
    elif(col == 27 and row in treeRowsTop):
        print 7
    # House 0
    elif (col == 35 and row in houseRowsZero):
        print 9
    elif (col == 36 and row in houseRowsZero):
        print 10
    elif(col == 37 and  row in houseRowsZero):
        print 11
    elif(col == 38 and  row in houseRowsZero):
        print 12
    # House 1
    elif (col == 35 and row in houseRowsOne):
        print 13
    elif (col == 36 and row in houseRowsOne):
        print 14
    elif(col == 37 and  row in houseRowsOne):
        print 15
    elif(col == 38 and  row in houseRowsOne):
        print 16
```

```
0
0
0
0
0
0
0
0
0
0
0
7
0
8
0
1
2
3
2
4
0
0
0
0
0
0
0
0
0
```

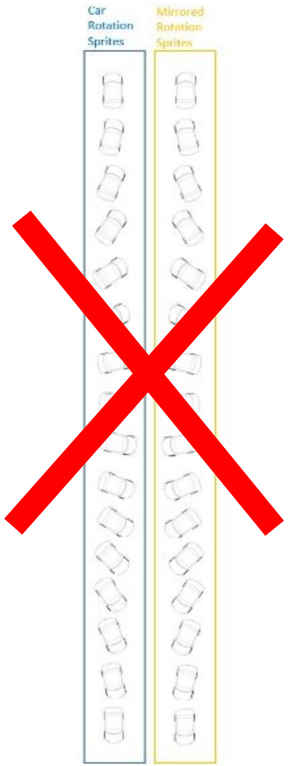
"trackXNames.txt"

```
for i in range(0, 256):
    if( i == 1):
        print "straightGrassLeft.png"
    elif (i == 2):
        print "roadTileWithoutLine.png"
    elif (i == 3):
        print "roadTileWithLine.png"
    elif (i == 4):
        print "straightGrassRight.png"

    elif (i == 5):
        print "tree-0-0.png"
    elif (i == 6):
        print "tree-0-1.png"
    elif (i == 7):
        print "tree-1-0.png"
    elif (i == 8):
        print "tree-1-1.png"

    elif (i == 9):
        print "TopRedHouse-0-0.png"
    elif (i == 10):
        print "TopRedHouse-1-0.png"
    elif (i == 11):
        print "TopRedHouse-2-0.png"
    elif (i == 12):
        print "TopRedHouse-3-0.png"

    elif (i == 13):
        print "TopRedHouse-0-1.png"
    elif (i == 14):
        print "TopRedHouse-1-1.png"
    elif (i == 15):
        print "TopRedHouse-2-1.png"
    elif (i == 16):
        print "TopRedHouse-3-1.png"
```

```
grassYellow.png
straightGrassLeft.png
roadTileWithoutLine.png
roadTileWithLine.png
straightGrassRight.png
tree-0-0.png
tree-0-1.png
tree-1-0.png
tree-1-1.png
grassYellow.png
grassYellow.png
grassYellow.png
grassYellow.png
grassYellow.png
grassYellow.png
grassYellow.png
grassYellow.png
grassYellow.png
grassYellow.png
grassYellow.png
```

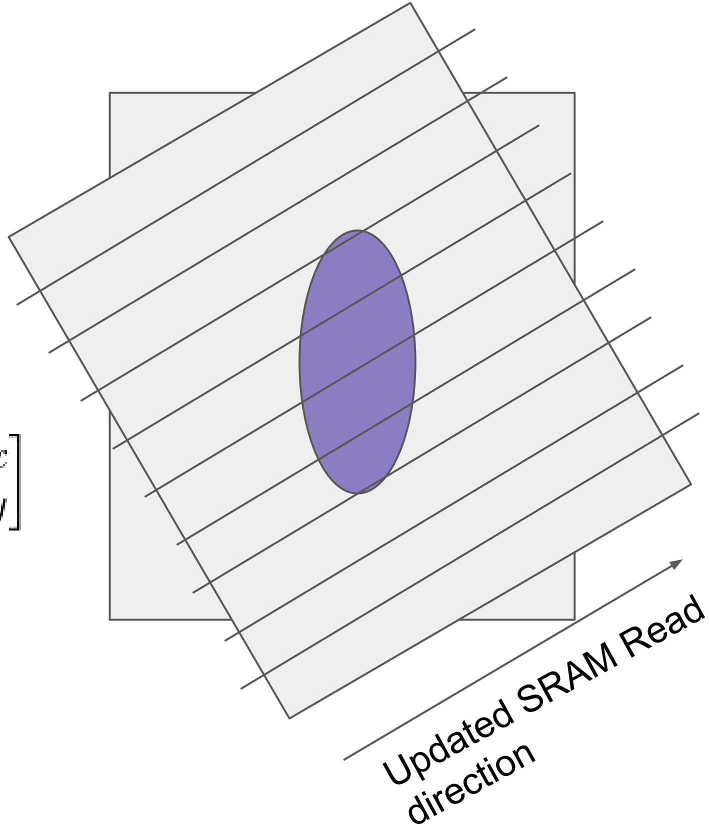
"trackXPatterns.txt"

Sprite Rotation - Rotation Matrix Approach



$$\begin{bmatrix} x' \\ y' \end{bmatrix} = \begin{bmatrix} \cos\theta & -\sin\theta \\ \sin\theta & \cos\theta \end{bmatrix} \begin{bmatrix} x \\ y \end{bmatrix}$$

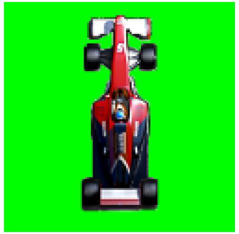
Wikipedia: Rotation Equation



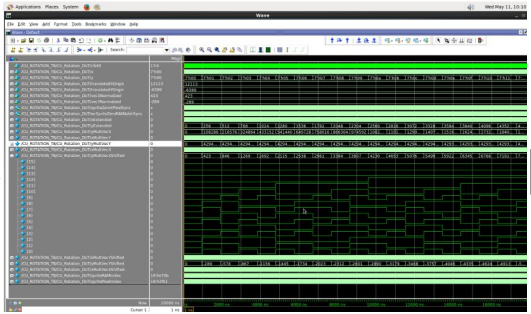
Sprite Rotation - Development Approach

1) High Level Software Algorithm POC

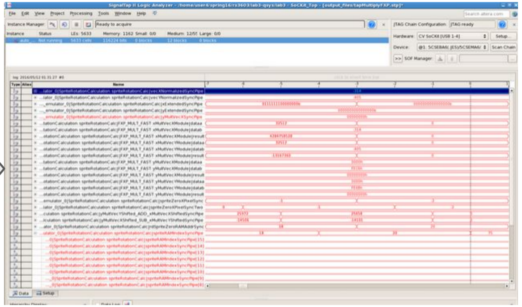
```
val theta = -.6
val rotationOriginX = -64 * math.cos(theta) - 64 * math.sin(theta)
val rotationOriginY = -64 * math.sin(theta) + 64 * math.cos(theta)
val translatedXOrigin = rotationOriginX  + 64
val translatedYOrigin = -(rotationOriginY - 64)

println("TRANSLATED ORIGIN Y" ++ translatedYOrigin.toString)
println("TRANSLATED ORIGIN X" ++ translatedXOrigin.toString)

val vecXNormalized = 2 * math.cos(theta)
val vecYNormalized = 2 * math.sin(theta)
```



2) System Verilog implementation + Modelsim Validation



3) Signal-Tap II Debugging of hardware realized solution



Lessons Learned

- Teamwork in an academic setting is difficult
    - Different experience levels, time commitments, interest etc. etc.
- Quartus II software has many quirks
    - X <= Y can yield unexpected results, sometimes it's better to manually index the bits you care about
    - Parameter constants can be different in the RTL viewer from what you would expect based on your System Verilog code
    - Warnings are almost too forgiving, some may be better to fail the compilation (net inferrence)
- Module based encapsulation is critical to help debug RTL code and allow for reasonable viewing of the system interconnections
- Signal Tap II is a crucial debugging tool, without it our project would have missed several desired deliverables.
- Open source drivers can be unpredictable to work with and be non-trivial to build for an embedded target