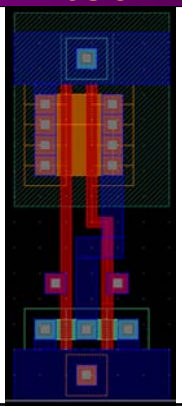
Where are we?

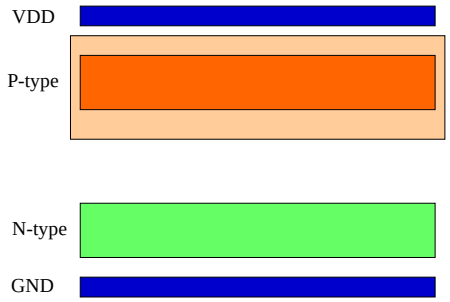
- Lots of Layout issues
  - Line of diffusion style
  - Power pitch
  - Bit-slice pitch
  - Routing strategies
  - Transistor sizing
  - Wire sizing

Layout - Line of Diffusion

- Very common layout method
  - Start with a “line of diffusion” for each type
  - Cross with poly to make transistors
  - This is the “type 2” NOR gate

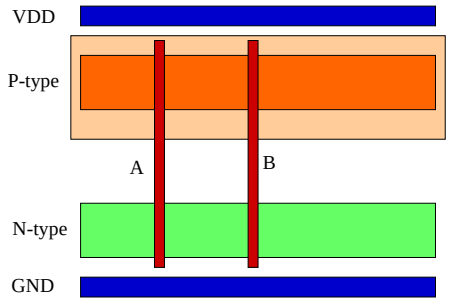


Line of Diffusion in General



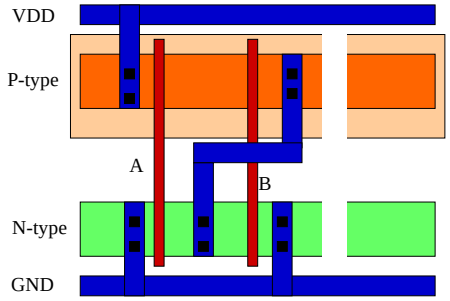
- Start with lines of diffusion for each transistor type

Line of Diffusion in General



- Cross with Poly to make transistors

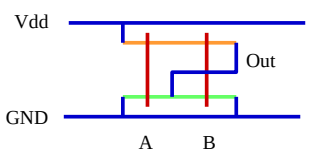
Line of Diffusion in General



- Now break and connect diffusion
  - There’s our NOR gate

Stick Diagrams

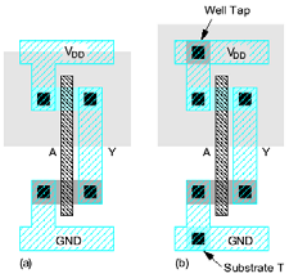
- You can plan things with paper and pencil using Stick Diagrams
  - You’ll need colored pencils
  - Draw lines for layers instead of rectangles
  - Then you can translate to layout



Gate Layout

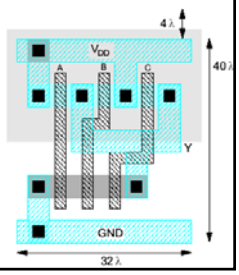
- Layout can be very time consuming
  - Design gates to fit together nicely
  - Build a library of standard cells
- Standard cell design methodology
  - V_{DD} and GND should abut (standard height)
  - Adjacent gates should satisfy design rules
  - nMOS at bottom and pMOS at top
  - All gates include well and substrate contacts

Example: Inverter



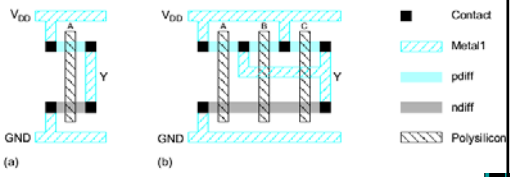
Example: NAND3

- Horizontal N-diffusion and p-diffusion strips
- Vertical polysilicon gates
- Metal1 V_{DD} rail at top
- Metal1 GND rail at bottom
- 32 λ by 40 λ



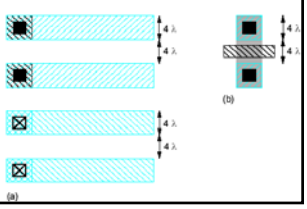
Stick Diagrams

- *Stick diagrams* help plan layout quickly
  - Need not be to scale
  - Draw with color pencils or dry-erase markers



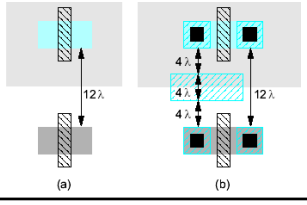
Wiring Tracks

- A *wiring track* is the space required for a wire
  - 4 λ width, 4 λ spacing from neighbor = 8 λ pitch
- Transistors also consume one wiring track



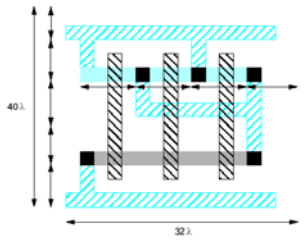
Well spacing

- Wells must surround transistors by 6 λ
  - Implies 12 λ between opposite transistor flavors
  - Leaves room for one wire track



Area Estimation

- Estimate area by counting wiring tracks
  - Multiply by 8 to express in λ



Example: O3AI

- Sketch a stick diagram for O3AI and estimate area
  - $Y = \overline{(A+B+C)D}$

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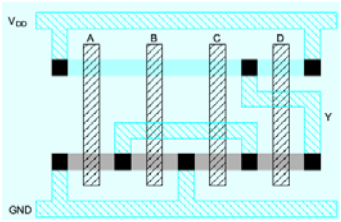

Example: O3AI

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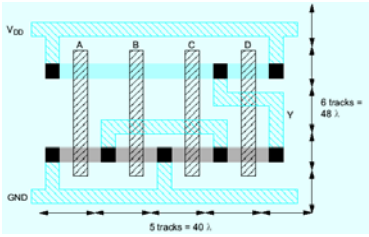
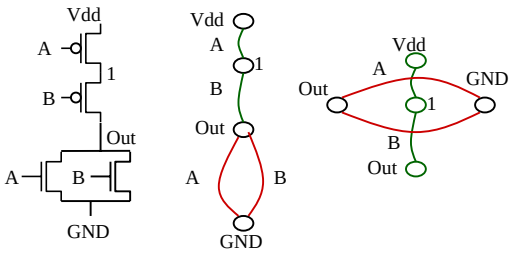


Euler Paths

- A graphical method for planning complex gate layout
  - Take the transistor netlist and draw it as a graph
  - Note that the pull-up and pull-down trees can be duals of each other
  - Find a path that traverses the graph with the same variable ordering for pull-up and pull-down graphs
  - This guides you to a line of diffusion layout

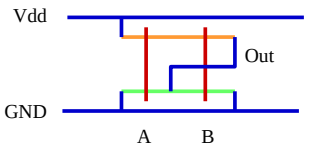
Simple example: NOR



- Euler path is a tour of all edges
- Find a path that has the same ordering for pull-up and pull-down, I.e. A B
  - Vdd A 1 B Out GND A Out B GND

This Path Translates to Layout

- Find a path that has the same ordering for pull-up and pull-down, I.e. A B
  - You can also include all the internal nodes
  - Pull-up: Vdd A 1 B Out
  - Pull-Down: GND A Out B GND
  - Line of diffusion layout

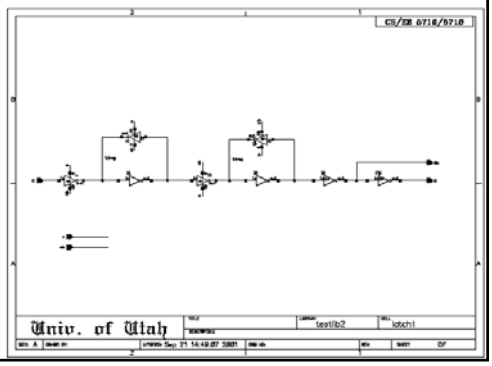


Examples

- Switch to chalkboard for examples
- Also chalkboard examples of latches and feedback

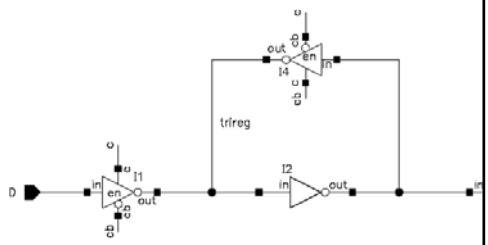
Layout Example: Flip Flop

- Simple D-type edge triggered flip flop



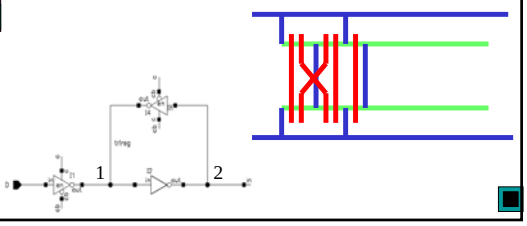
Zoom in on Latch

- Need two copies of this for a full D flip flop



Stick Diagram of Latch

- First add the gates
  - Note where outputs can be shared
  - Ignore details of signal crossings for now…



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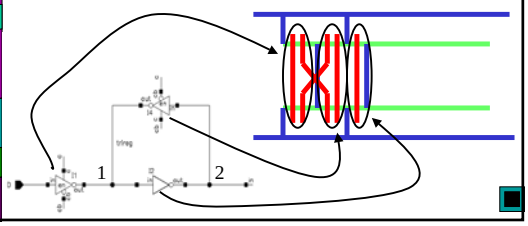
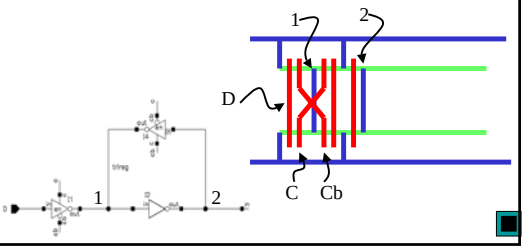


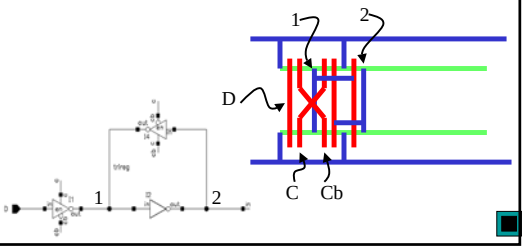
Stick Diagram of Latch

- First add the gates
  - Note where the signals are relative to the schematic



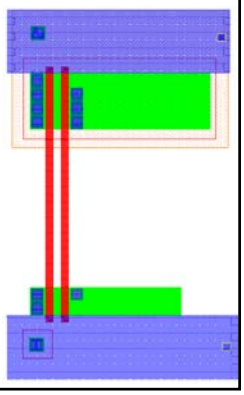
Stick Diagram of Latch

- First add the gates
  - Note where the signals are relative to the schematic
  - Note where additional connections are needed



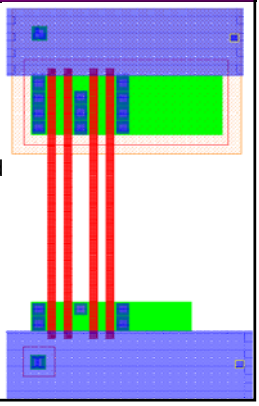
Start With First Enabled Inv

- I'm using 5u power wires, 29u vertical picth based on the C5x standard cell model
  - Probably overkill…
- Add DIF for N- and P-type transistors
  - Note 2x standard size because of serial connection

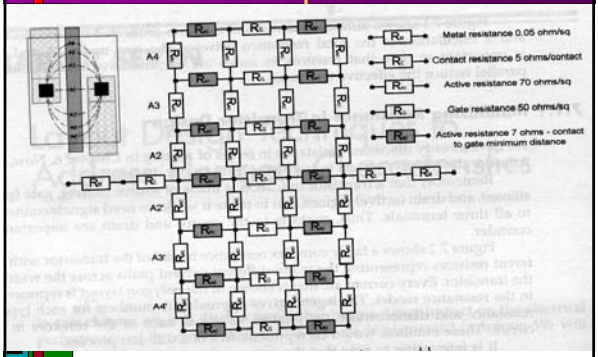


Add Next Enabled Inverter

- Add two more poly gates for second enabled inverter
- Note that the two enabled inverters share an output (not connected yet)
- Note that I've added vdd! and gnd! For DRC
- I'll deal with C-Cb crossover later…

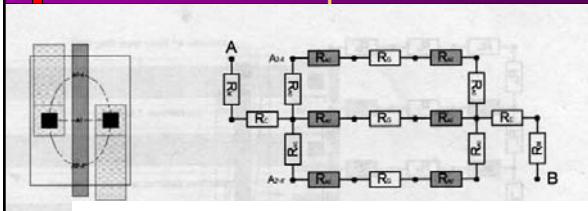


Aside: Multiple Contacts



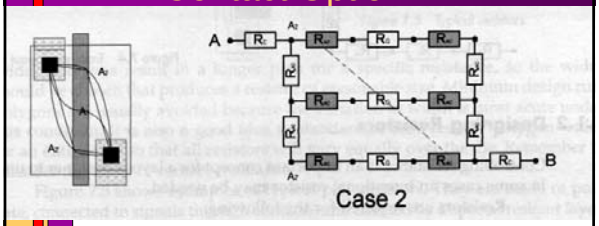
- Look at a model of transistor resistance

Contact Option #1



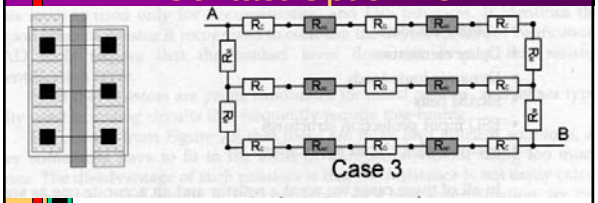
- Total equivalent resistance = 56.1 Ohms
  - Metal resistance = 0.05 O/square
  - Contact resistance = 5 O/contact
  - Active resistance = 70 O/square
  - Gate resistance = 50 O/square
  - Active resistance 7O - contact to gate

Contact Option #2



- Total equivalent resistance = 105.1 Ohms

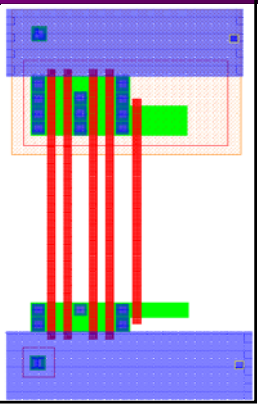
Contact Option #3



- Total equivalent resistance = 24.7 Ohms
- So, put in as many contacts as will fit along side a wide gate…

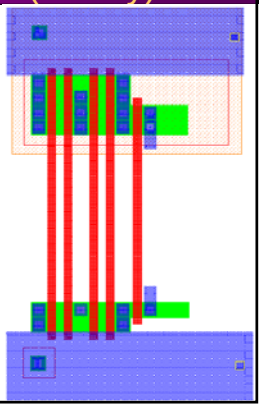
Meanwhile, Add inverter

- Note that it's back to standard size
- Shares vdd/gnd connection with enabled inverter
- Minimum spacing for all transistors so far
  - Incremental DRC at EVERY step!



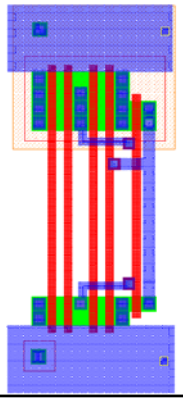
Finish Inverter (mostly)

- Make inverter output connections
  - Don't connect yet
  - I'm going to use M1 as a horizontal layer
  - Which means being careful about vertical use of M1



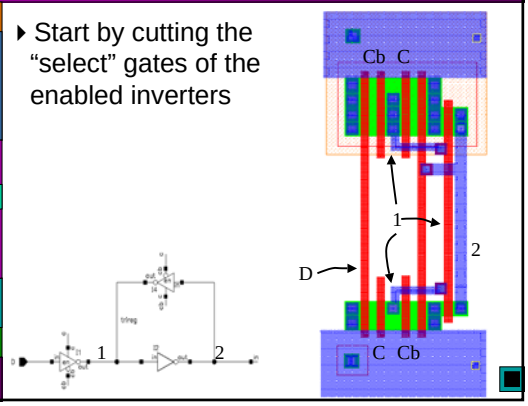
Make Feedback Connections

- Output of inverter (connected in M1 for now) goes to input of 2nd enabled inverter
- Output of enabled inverters goes to input of inverter
  - Note that outputs of enabled inverters goes through POLY



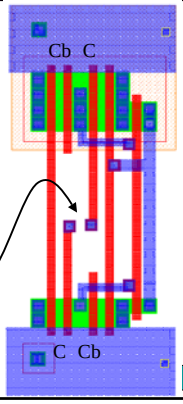
Deal With C/Cb Crossover

- Start by cutting the "select" gates of the enabled inverters



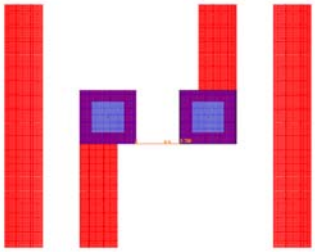
Connect the C Input

- Prepare for M1 crossover in C wire
  - C is N-type in first enabled inverter, P-type in second enabled inverter
  - Use M1PLY contacts
- PROBLEM! We need to squeeze a poly wire inbetween those contacts…
  - Use design rules to plan for space



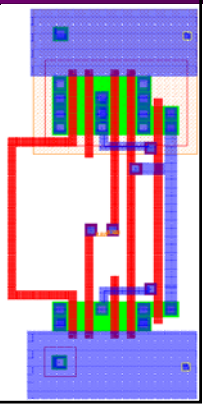
Look at Gap

- You need to have enough space for minimum width poly to fit through gap

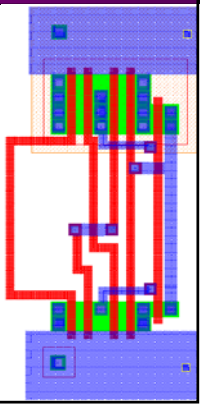


Start Making Room

- Push D-signal poly out of the way with minimum spacing to DIF
  - We'll move it back later
- Make sure to continue to DRC at every step!

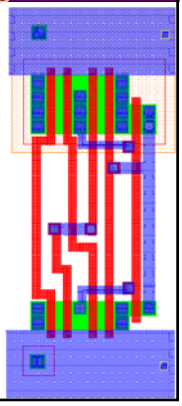


Jog the poly around and through the gap with minimum spacing to M1PLY contact on both sides



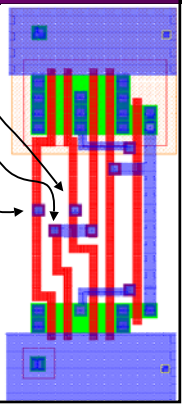
Fit Things Back Together

- Now put big D-poly jog back as close as you can



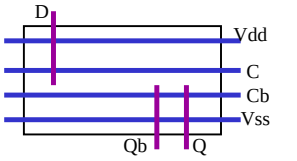
Add M1PLY contacts for future connections

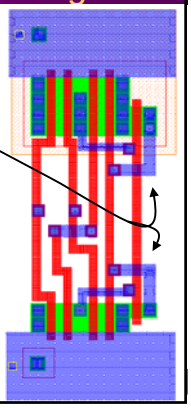
- Need to get Cb, C, D signals into the latch in the future
- Those will most likely be routed on some type of metal
- So we need the M1 metal connection at the bottom



Plan For Clock Routing

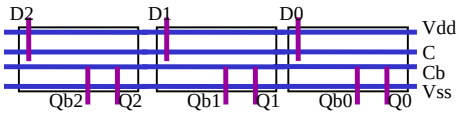
- Break M1 output connection on inverter to leave room for horizontal M1 routing
  - I'll eventually route C and Cb through the cell horizontally on M1





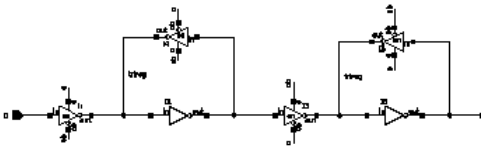
Bit Slice Plan

- Plan is to stitch these together to make a register
  - Inputs on top in M2
  - Outputs on bottom in M2
  - Clock and Clock-bar routed horizontally in M1



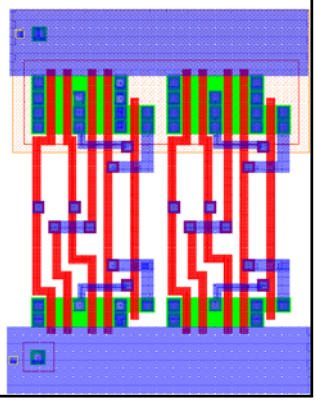
Need Second Latch

- Basically a copy of the first latch
  - But with reversed C and Cb connections
  - Copy the first layout…



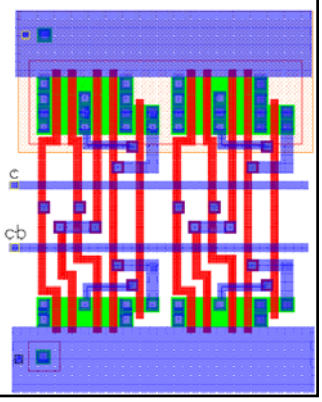
Expand from Latch to F/F

- Select and copy the first latch
- Now I need to reverse the C and Cb connections



C/Cb Routing Plan

- Remember my C/Cb routing plan
  - Plan for where those wires can go



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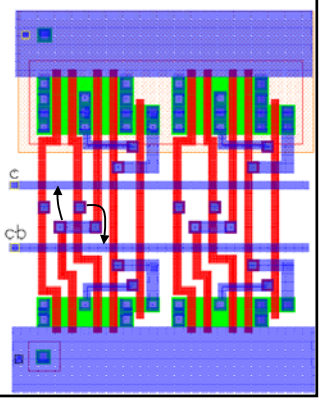
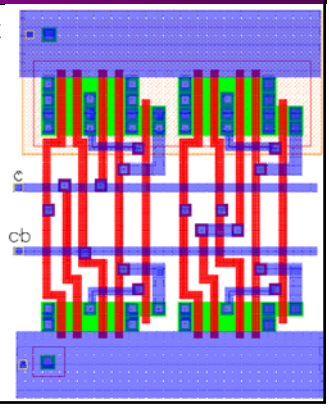


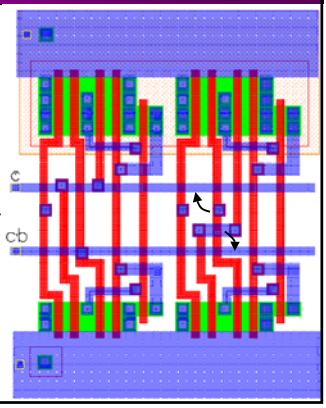
Connect Clocks to 1st Latch

- Adjust contact positions for the first enabled inverter



Connect Clocks to 2nd Latch

- Now shift the contacts the other way for the second latch
  - Makes the complementary C/Cb connection



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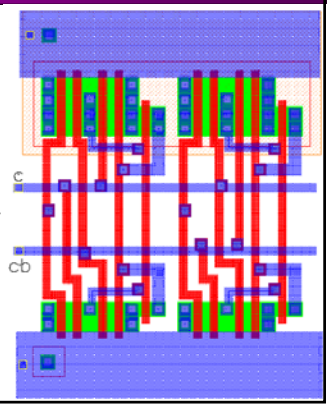
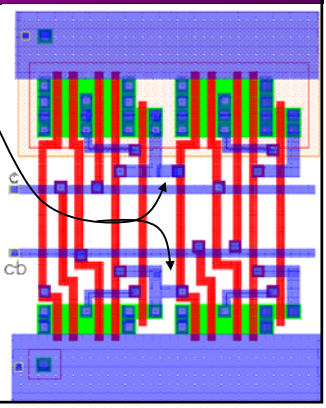
- Now shift the contacts the other way for the second latch
  - Makes the complementary C/Cb connection



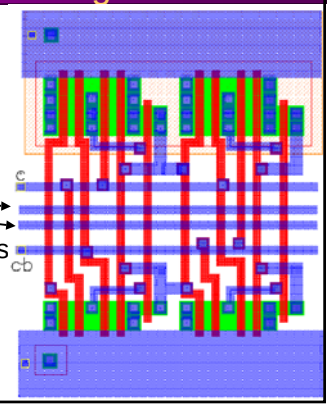
Connect the Two Latches

- Q of first goes to D of second
  - Don't really need both top and bottom connections, but it doesn't hurt
  - Lower resistance paths



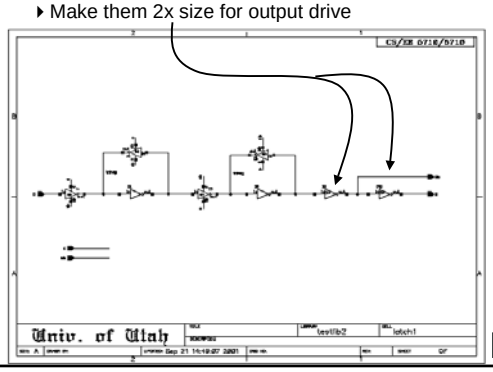
Note Extra Routing Channels

- Note that this vertical pitch, and this cell contents have left two additional M1 horizontal routing channels through the middle of the cell



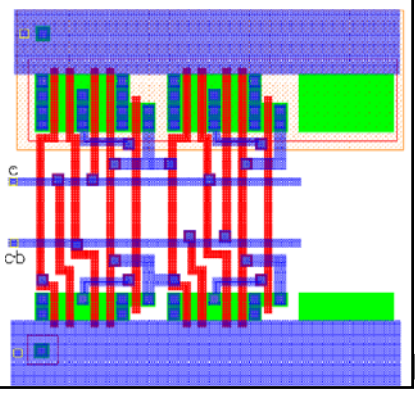
Now Consider Output Inverters

- Two more inverters
  - Make them 2x size for output drive



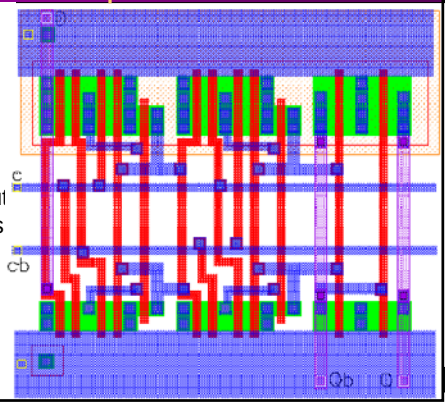
Output Inverters

- Add the DIF for the output inverters
  - Remember I want to make them 2x size



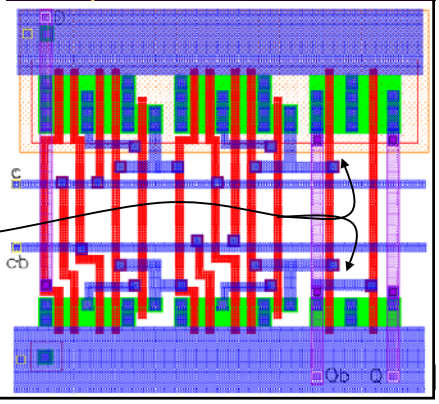
Make Output Connections

- Add vdd, gnd and output contacts
- Add poly gates
- Make output connections in M2
- Connect to 2nd latch and to 2nd inverter



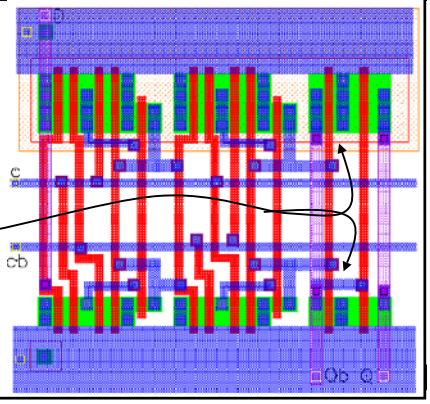
Now Squeeze Inverter

- Select regions of the layout and stretch to move it all to a new spot



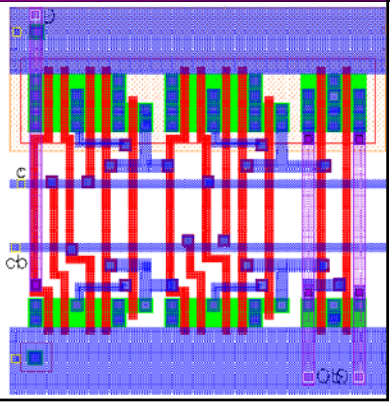
Keep Squeezing

- Now squeeze power supply contacts



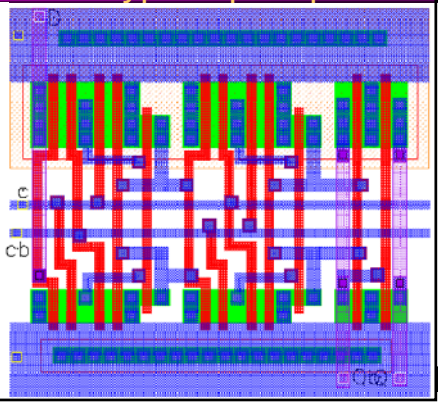
Squeezed Version

- Output inverters squeezed together
- Note that D, Q, And Qb are routed vertically in M2

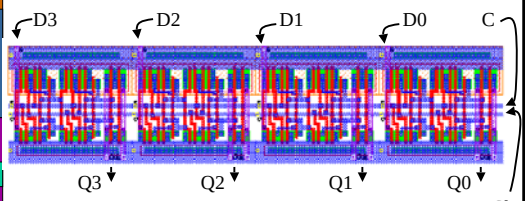


Final D-Type Flip Flop

- Squeeze vertically since I don't need extra routing channels, and I don't need to match with standard cells
- Add long TUB and SUB contacts

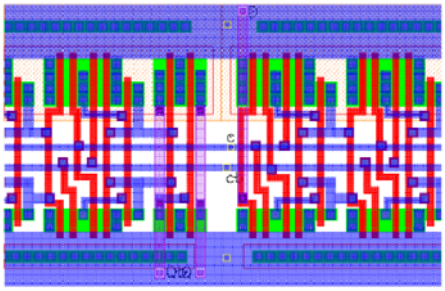


Put Four of them Together



- Add instances that abut
  - Or use the “array” feature of the instance dialog
- Note that C and Cb are routed in horizontal M1

Zoom in to Cell Boundary



- There’s a little extra space
  - Caused by wanting each latch to DRC on its own
  - Could close this up by overlapping cells