# Optical Interconnection Device Based on the White Cell

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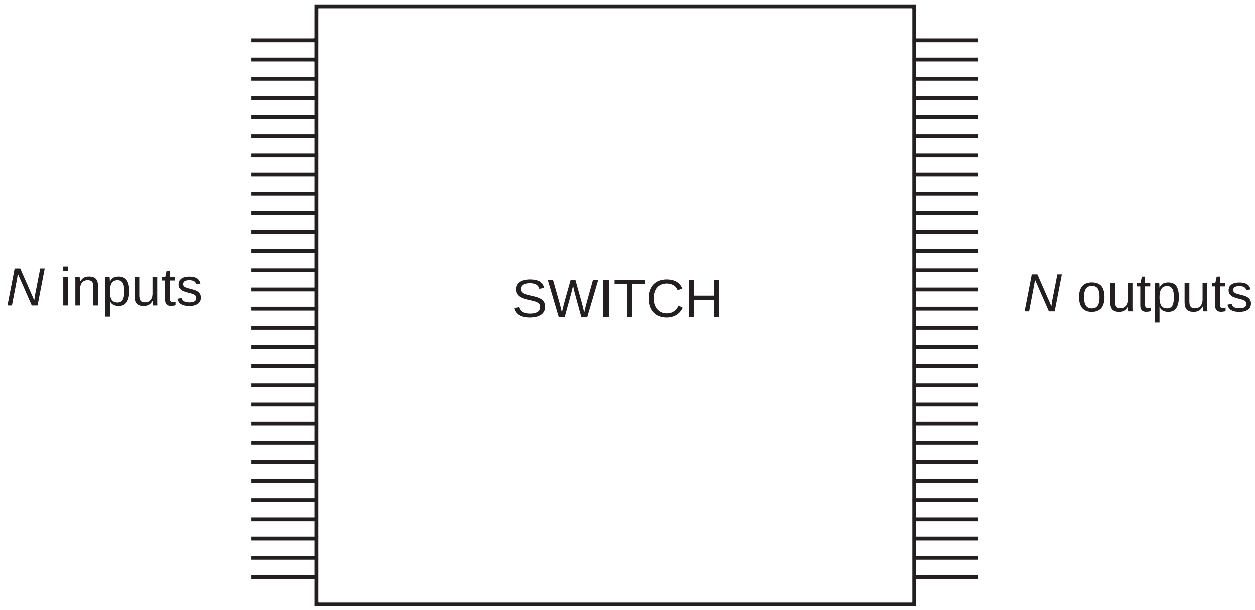
# Goal:

- Optical interconnection
- Strictly non-blocking
- Reconfigurable
- Large numbers of inputs and outputs

# Our approach:

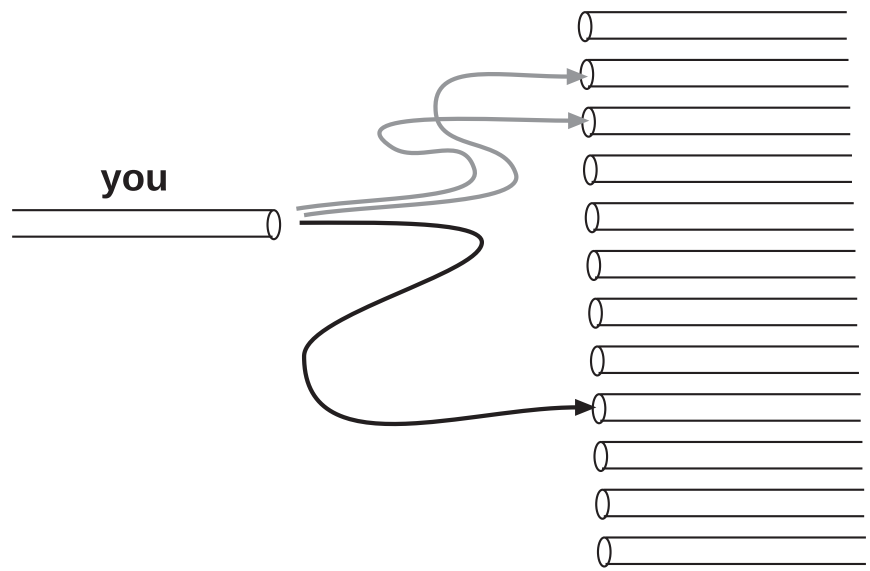
- The White cell

# The problem:

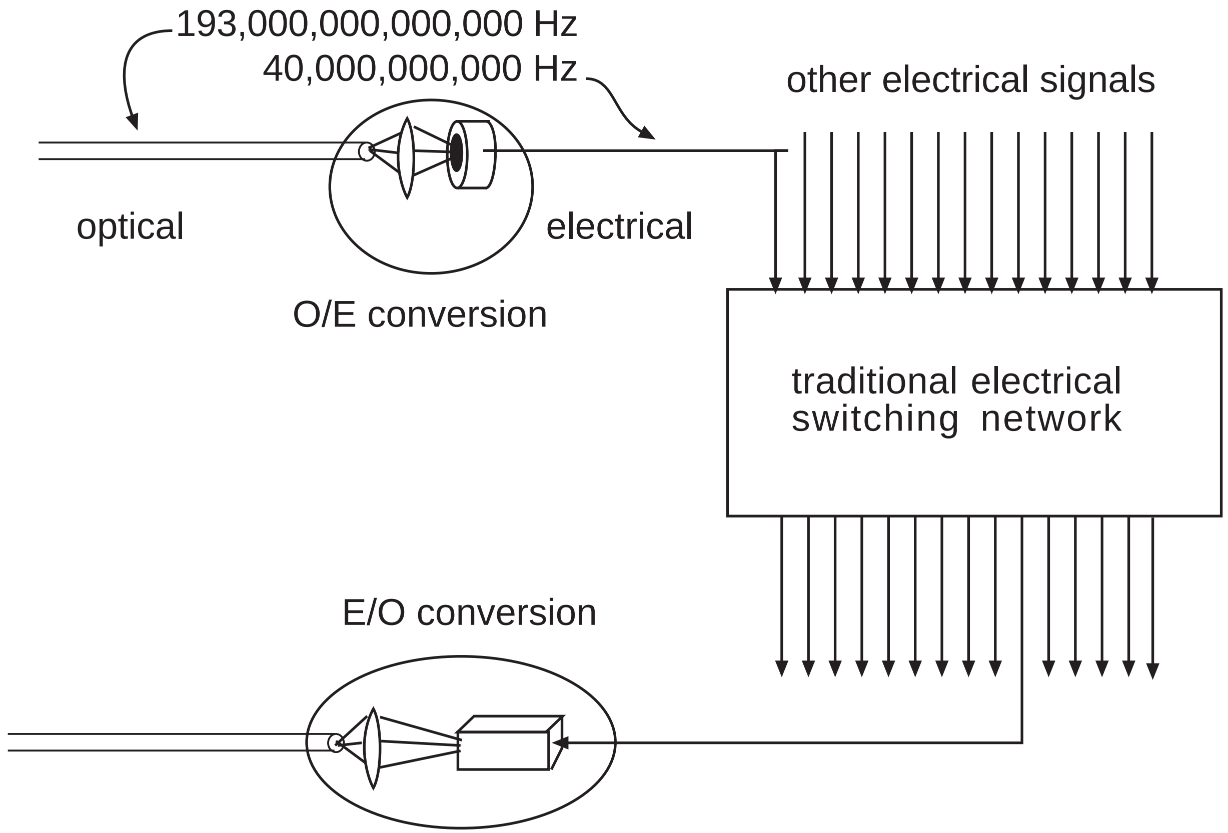


# In the optical domain

- Need to connect one fiber to any of a bunch of others
- Need to be able to change connection at any time
- Your connection cannot block anyone else's

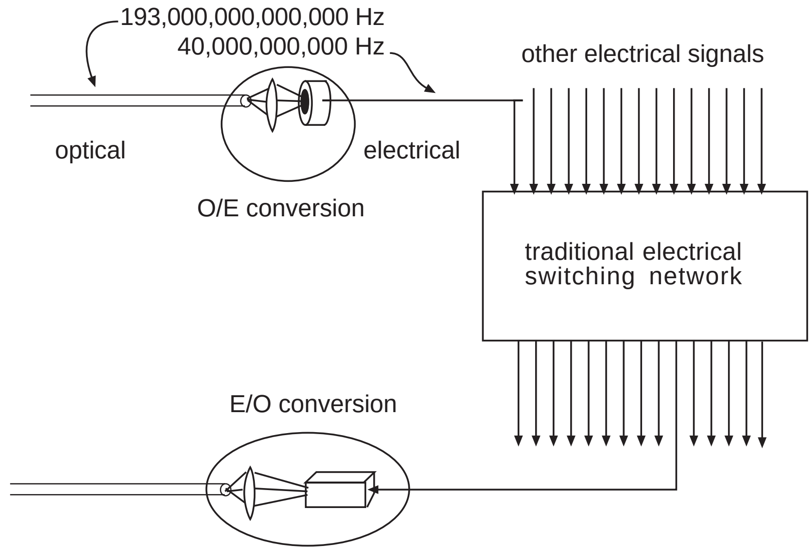


# Don’t want to convert to electrical domain



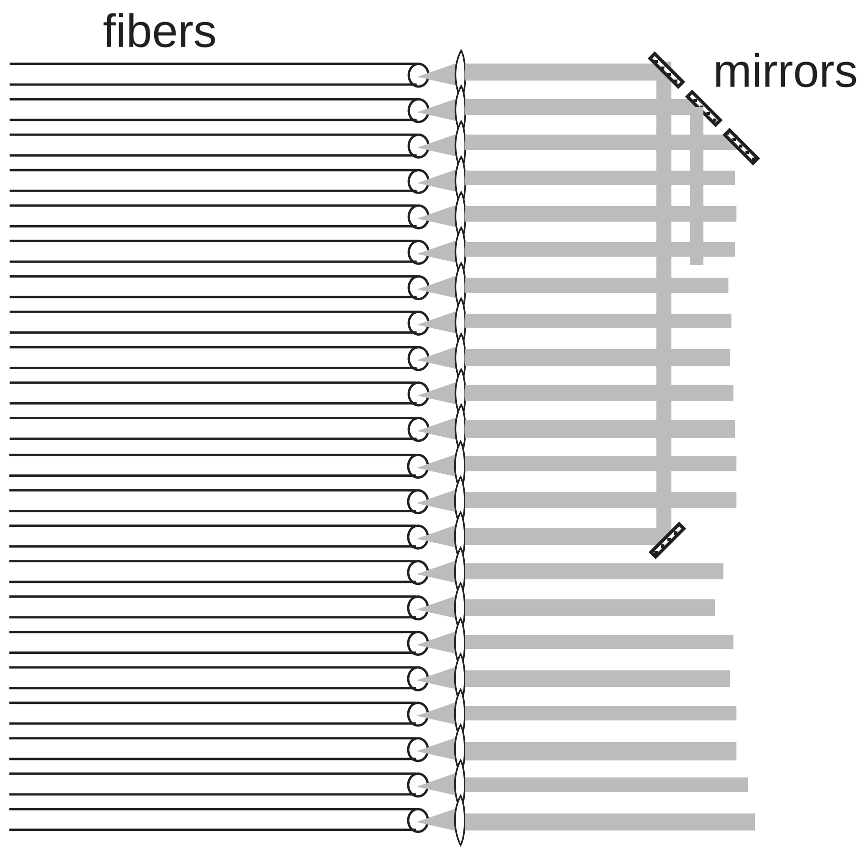
# Reasons it's bad:

- Need detector, laser for each link
- Electrical lines slow
- Light can travel both ways on a fiber but electricity can't
- Can have many signals on a single fiber- not so on a wire



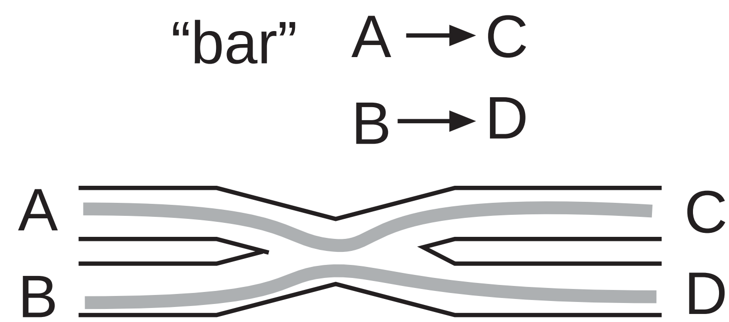
# Preferred: Stay optical

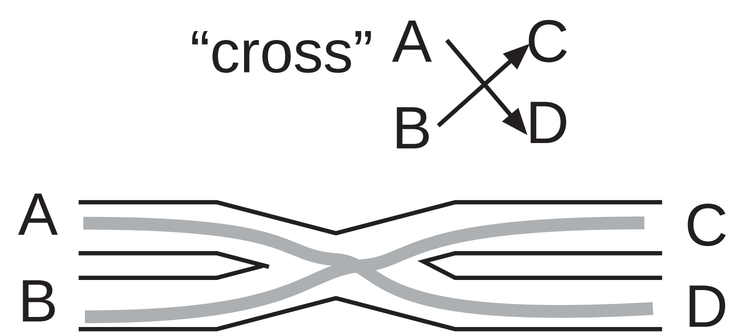
- For example some sort of mirror array
- Have to be able to change mirrors or switch light somehow



# Older approach:

- Waveguide switches
- Electrically controlled
- Have to be very long (small angles)
- Various types of switches

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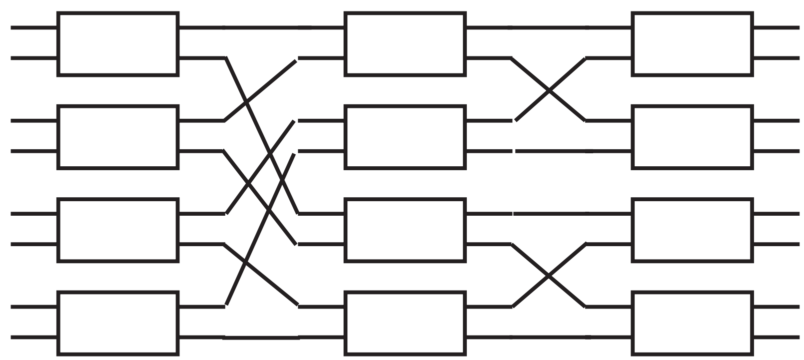
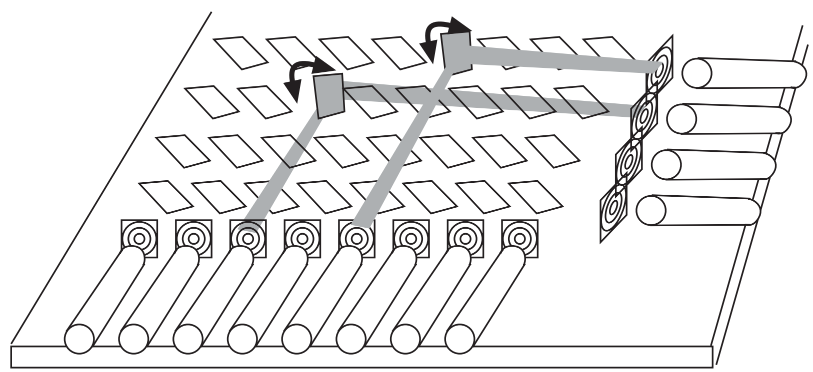
# Hard to scale up

- Have to add a column of switches for every four inputs you add
- Largest demonstrated of this type is 48x48



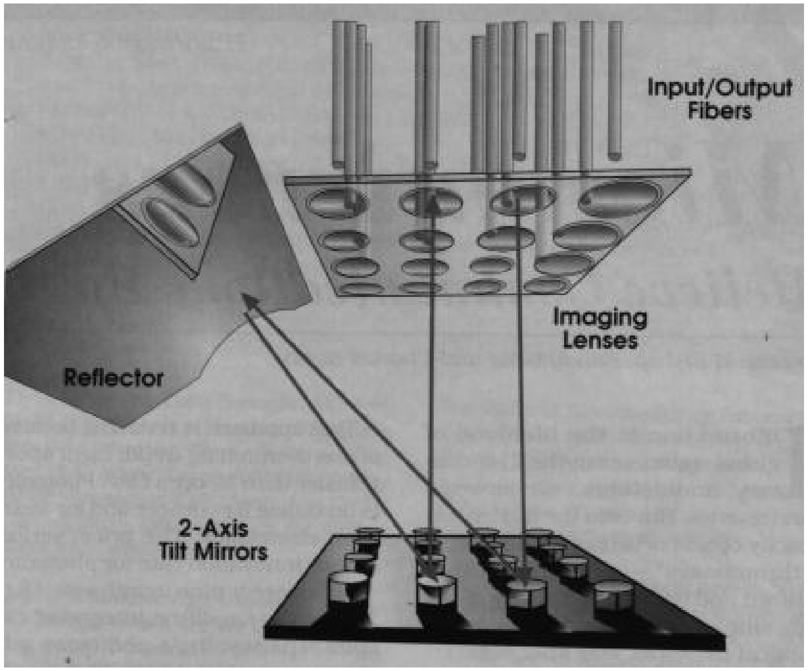
# An actual mirror approach

- From MIT
- High neatness coefficient- mirrors pop up and down
- Turns out the pop-up lenses are too lossy (97% loss total)



# Here's what Lucent did

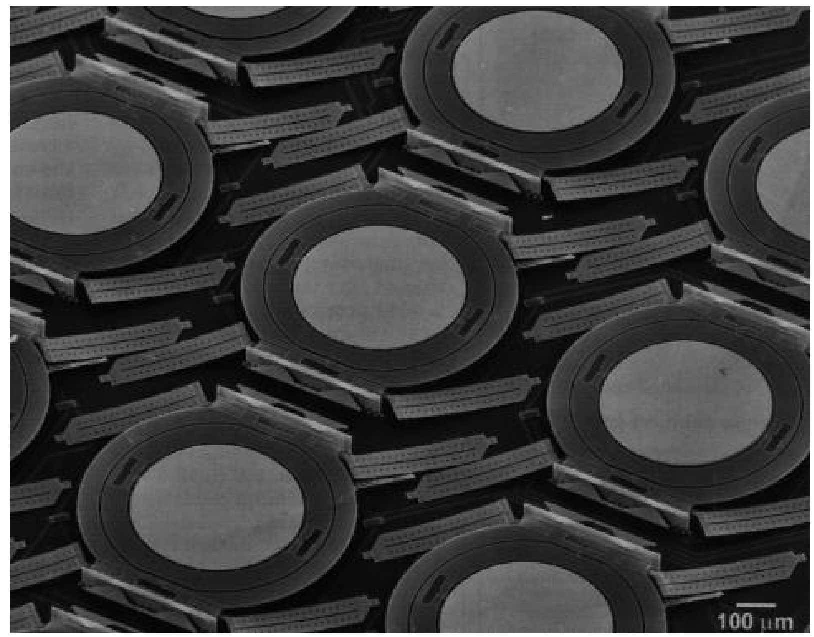
- Uses an optical MEM (micro-electro-mechanical) micromirror array
- Requires precise alignment and calibration
- Had a 256x256




Photonics Spectra, March 2000, Laurin Publishing

# Their MEM:

- 256 micromirrors
- Each 1/4 mm across
- Can tilt to any position within a certain cone
- Analog as opposed to digital: zillions of positions

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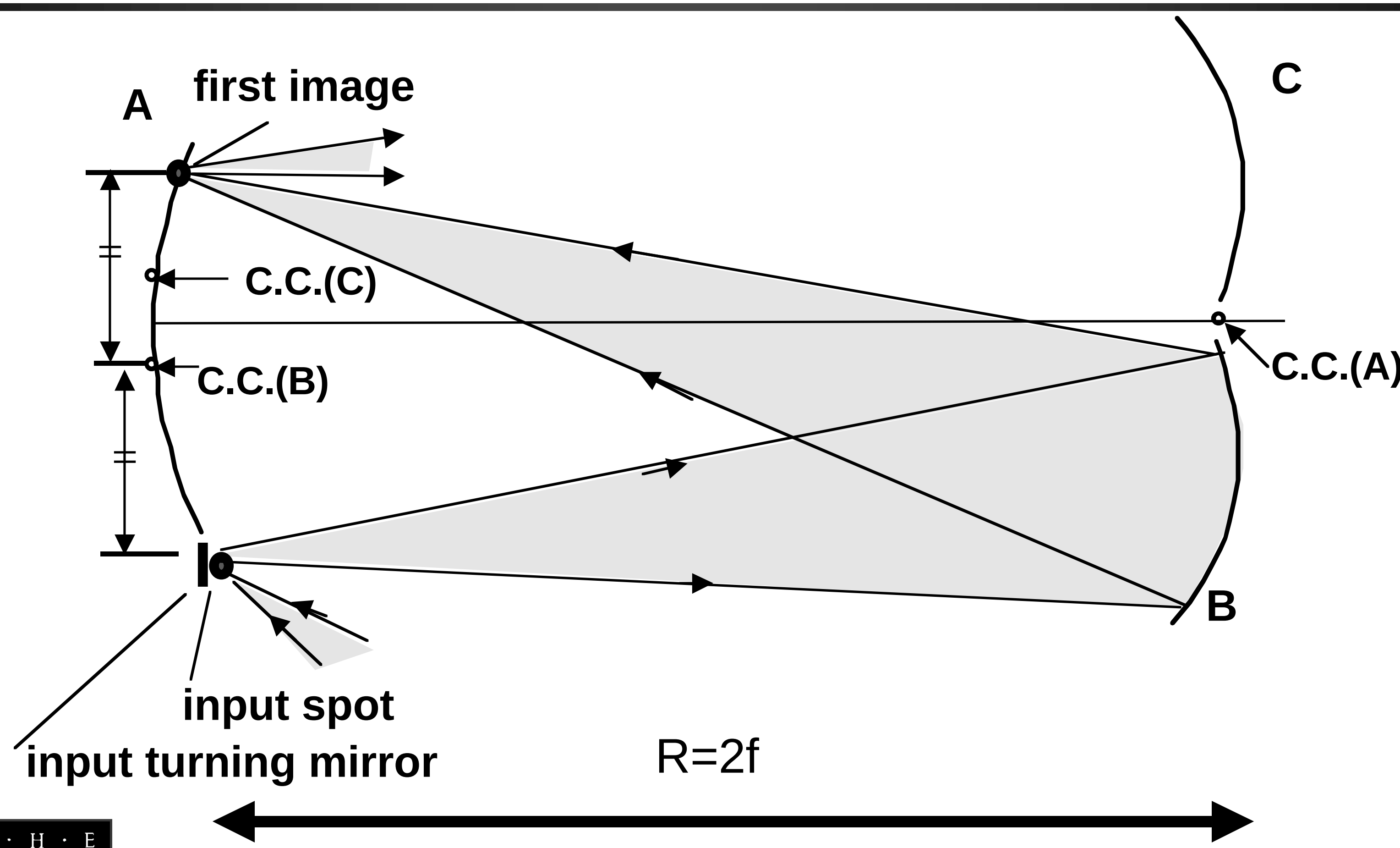
# Our Approach

- Free-space and 3-D
  - » Easier to scale
- Multiple bounces in a “White cell”
  - » Use a MEM micromirror array to switch beams
- Has built-in redundancy

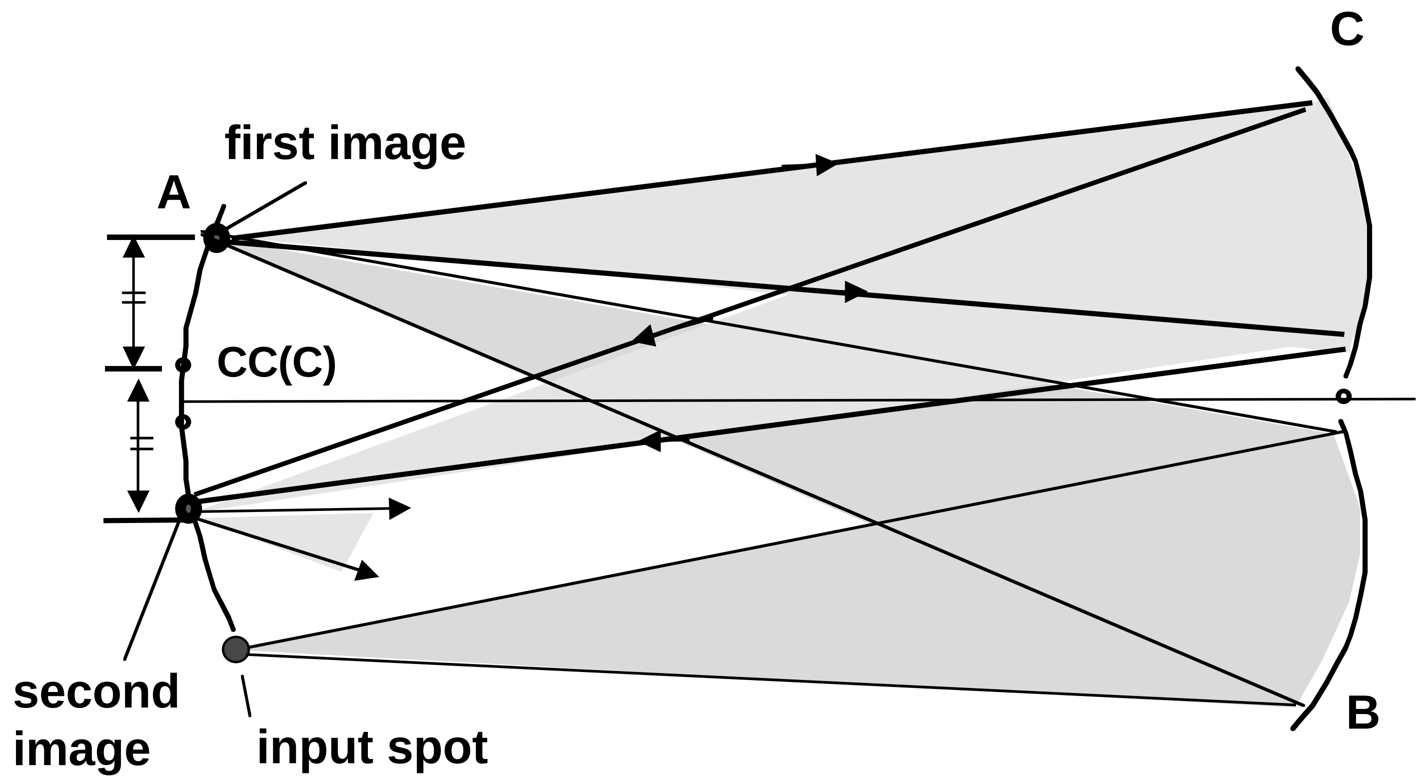
# Organization

- Review of the White cell
- Examination of the spot patterns: the key
- Adapting the White cell to optical interconnections
- Proof-of-concept in lab

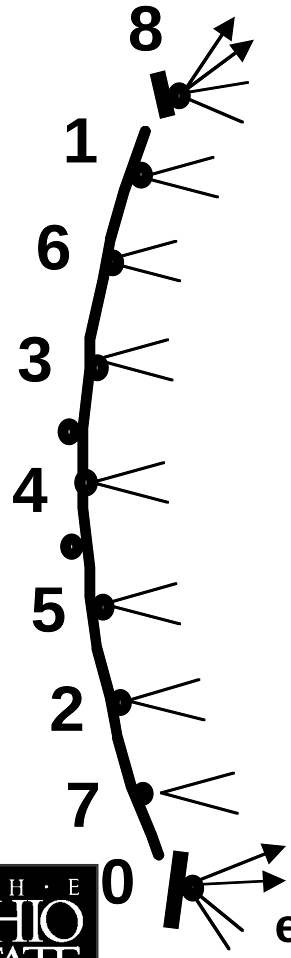
# White cell: three identical spherical mirrors



# Process produces set of spots

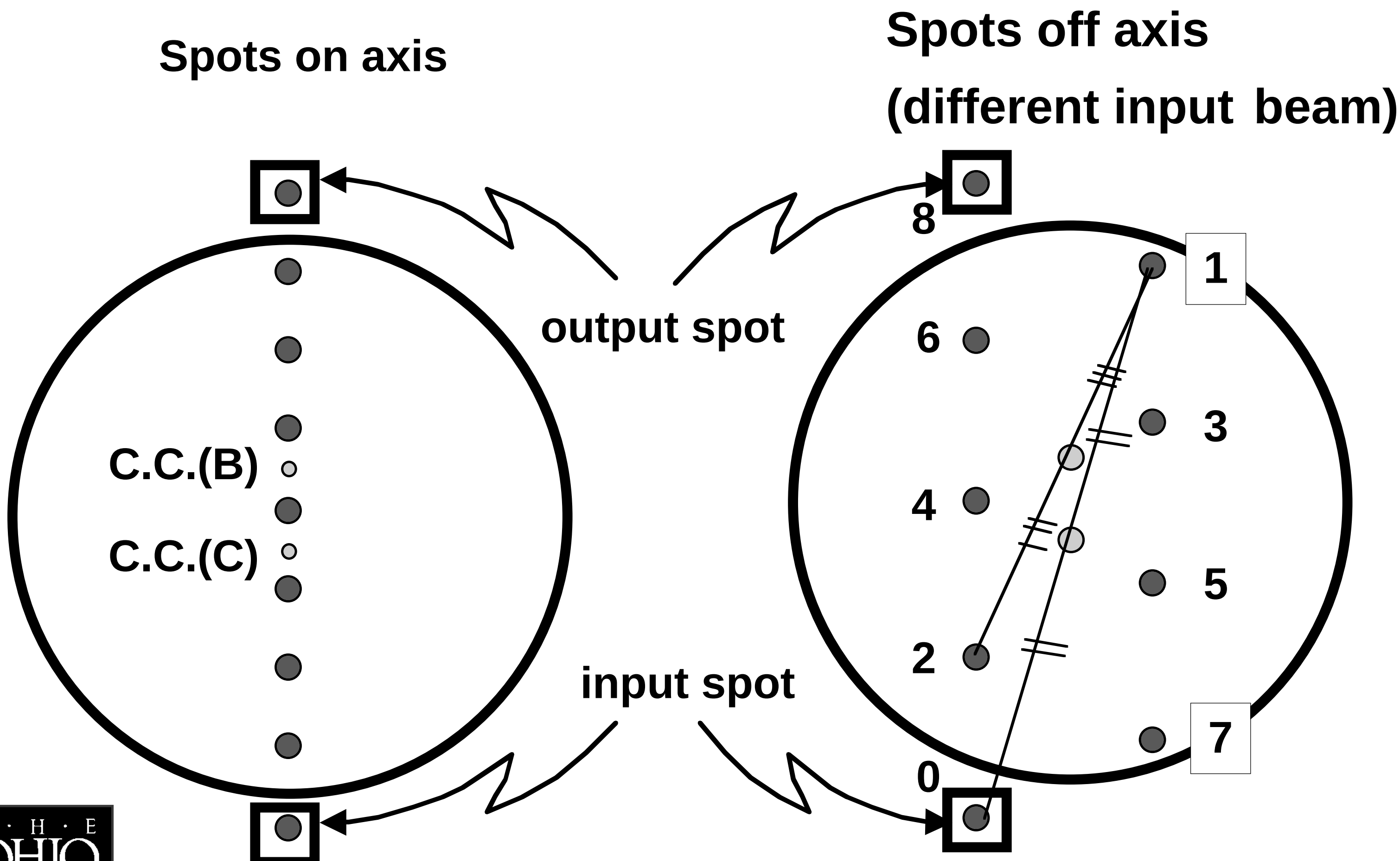


# Sequence of Spot Images (for one input beam)

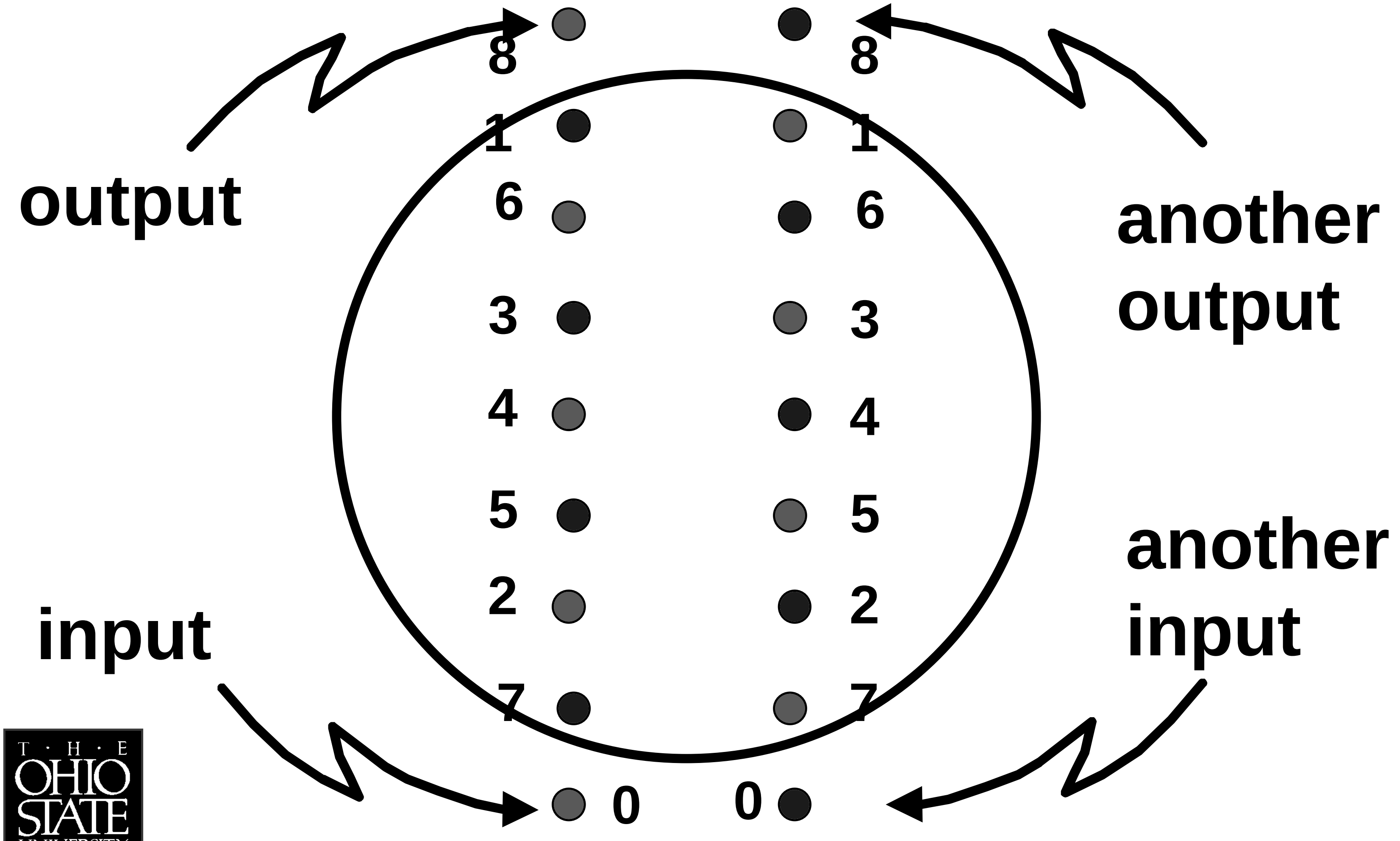



- **no divergence problem**
- **diffraction limited**
- **compact**

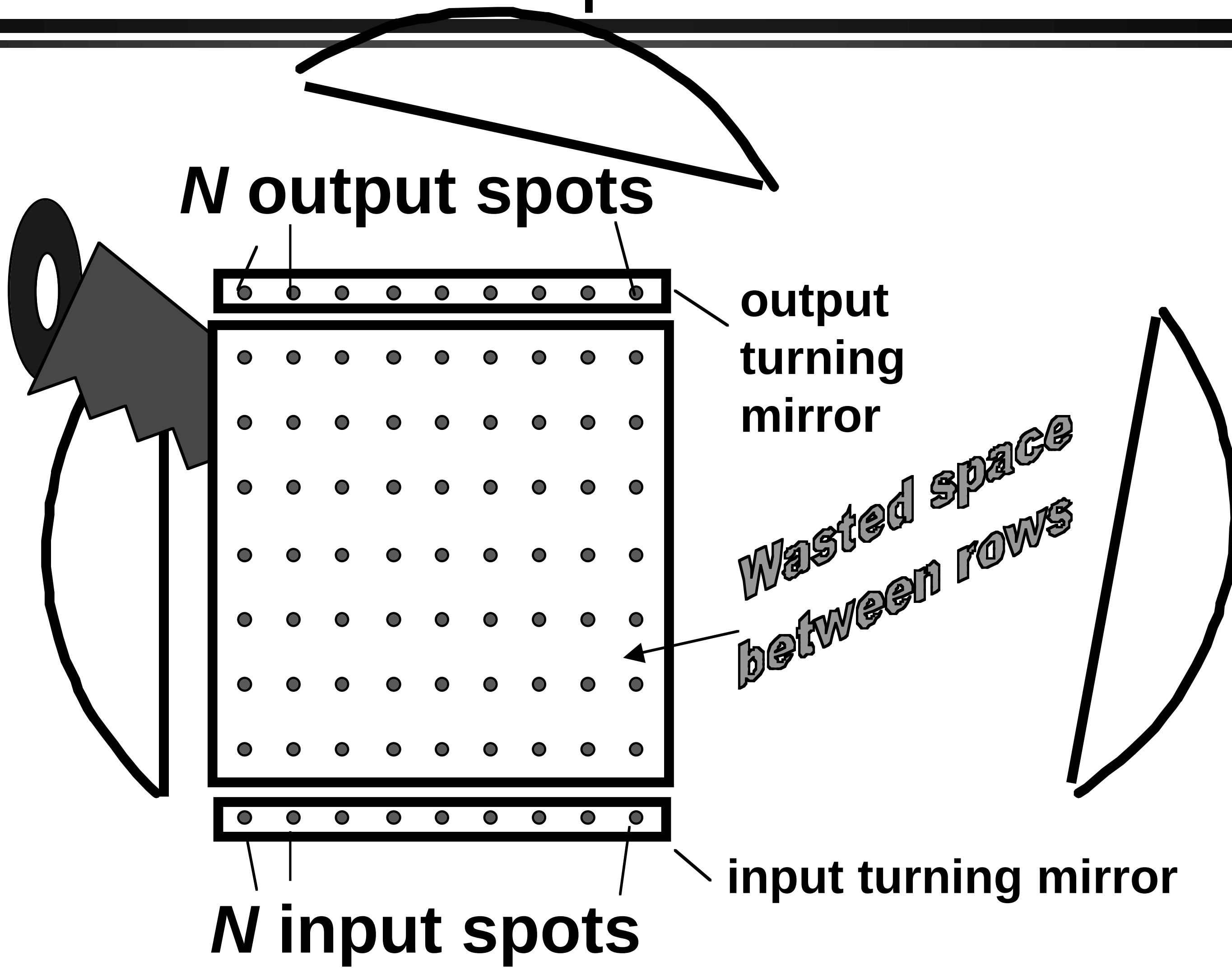
# More than one pattern possible



# Interleaving Spots

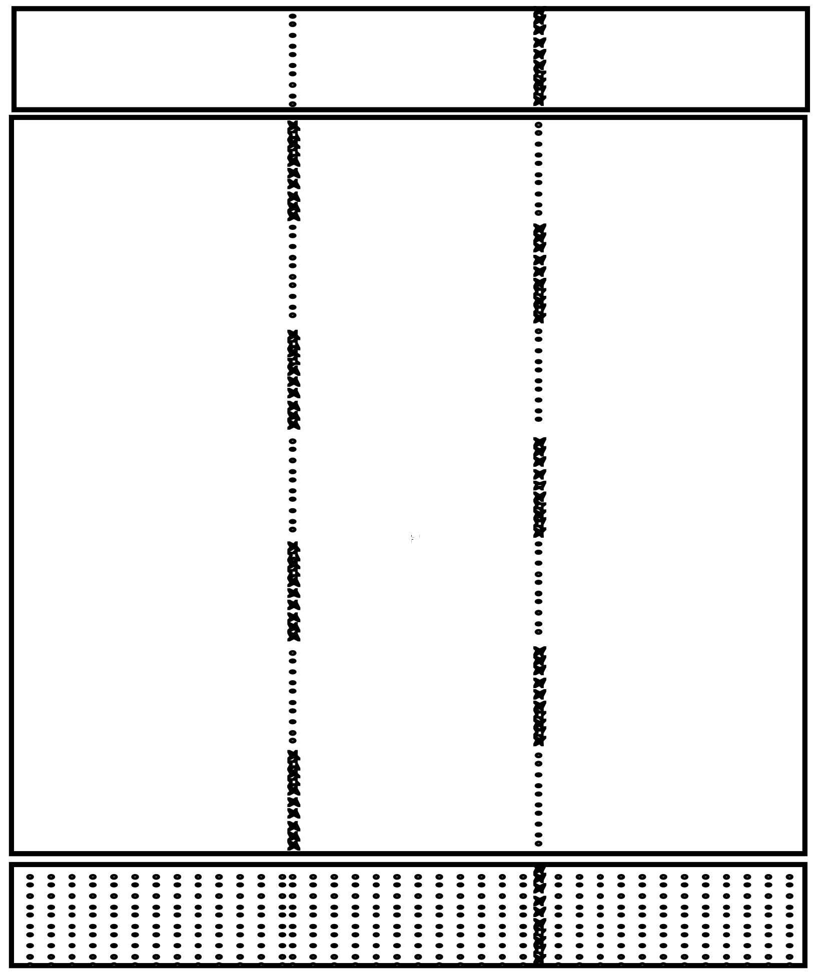


# Replace mirror with MEM- spots will land on pixels



# Zillions of input spots

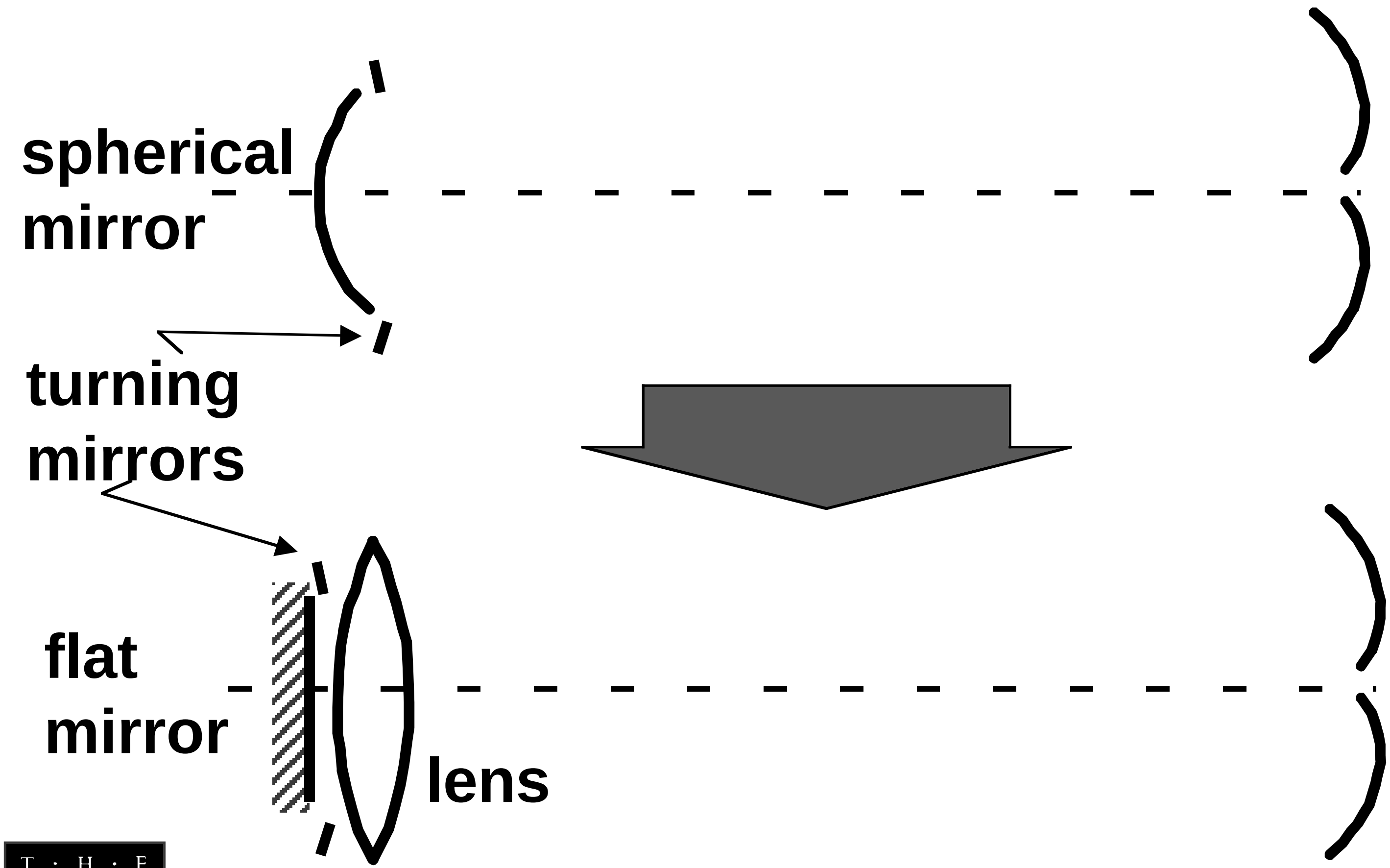
- Want to fully exploit available pixels



# Consider TI DMD

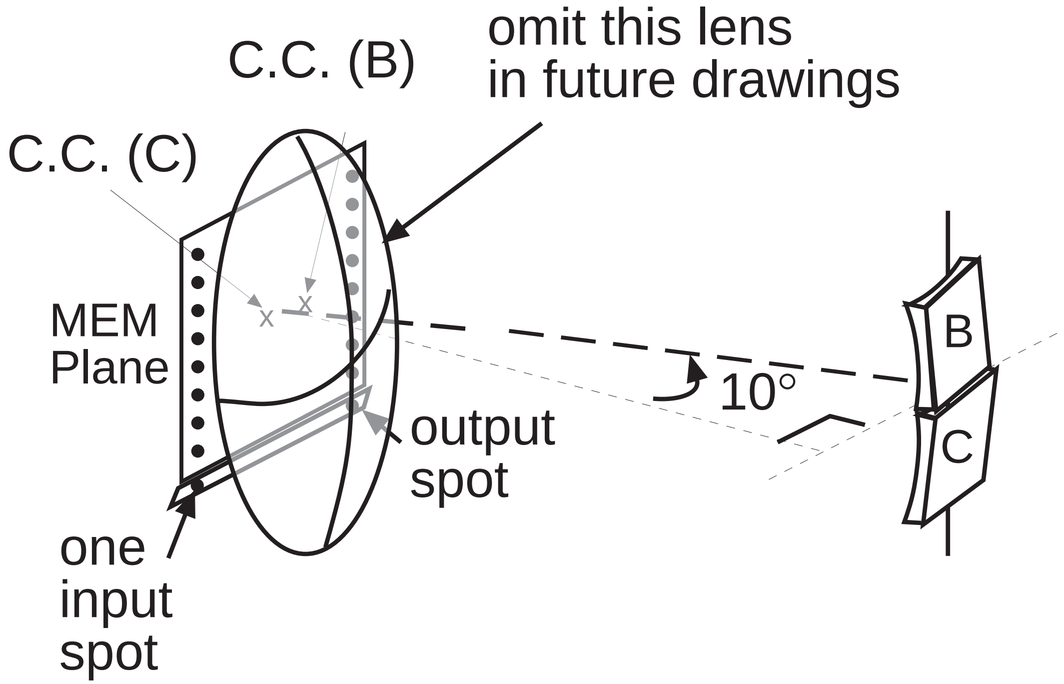
- The only one we could get our mitts on
- Lots of pixels (786,000 for medium one)
- Each micromirror can tilt to ±10°
- Need to put this into a White cell

# Improved White Cell



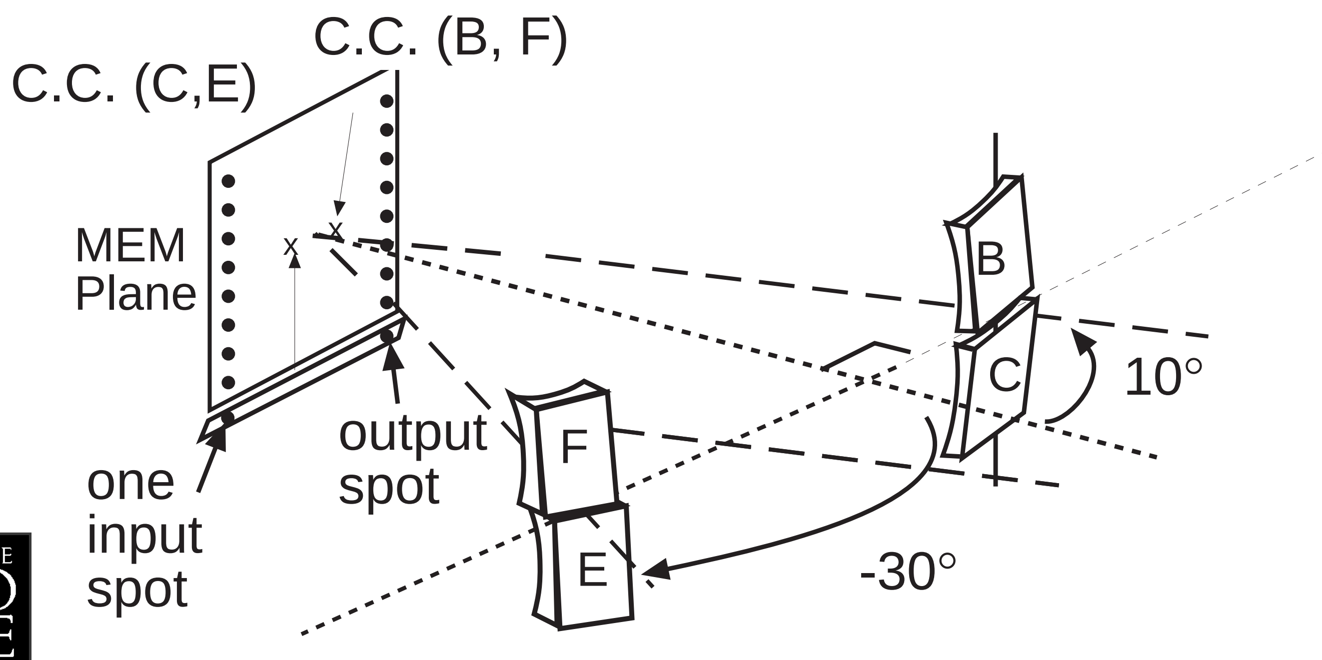
# Flat mirror becomes MEM

- Suppose all mirrors tilted at +10°
- Can create a White cell



# Now suppose a pixel tips down

- Add another pair of mirrors
- Now have multiple White cells (BC, BE, CF)
- Can switch to either arm on each bounce

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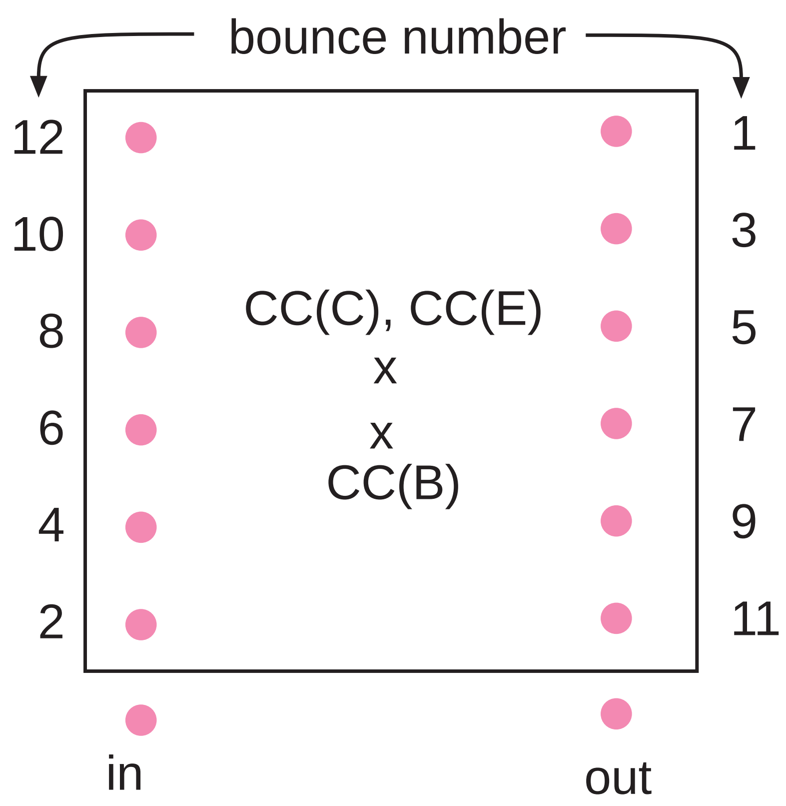
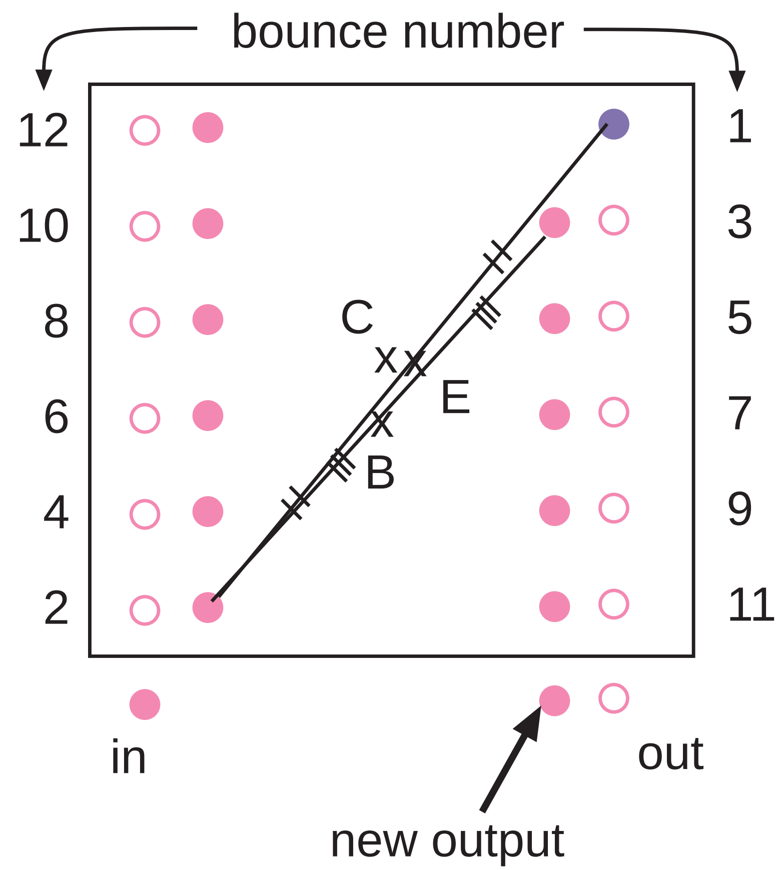
# Suppose E aligned like C

- Beams can go to either E or C on every other bounce
- Spot pattern is maintained regardless of path
- Beam exits at same point regardless of path (not useful yet)



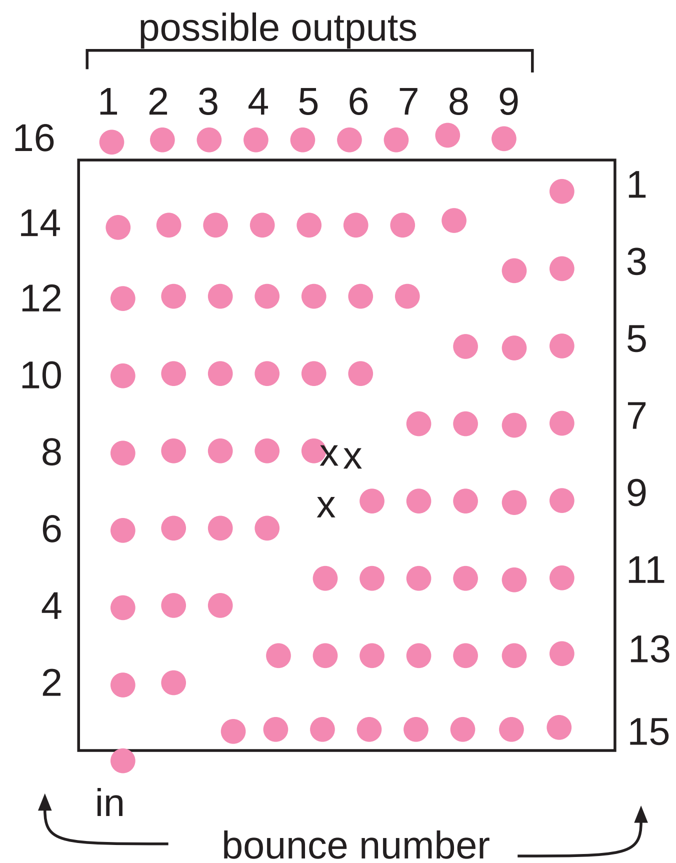
# But, suppose E is misaligned

- Let beam go to E on first bounce
- Purple pixel is “switched”
- Rest of time beam remains in BC White cell
- Beam comes out in a new place



# Result

- Each time a beam is sent to E, it moves over one column
- Number of possible outputs controlled by number of pixels and number of bounces
- Here 16 bounces=9 outputs



# Number of outputs *N*

- *N* is based on available pixels
- Number of pixels required per input for *NxN*

$$N^3 + 3N^2 + 2N$$

- TI's medium DMD: 1024x768=786,000 pixels
- Thus 91 inputs and 91 outputs are possible

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# The good news

- Small component count
- Alignment is simple- only need to align three mirrors
- Insensitive to micromirror pointing errors

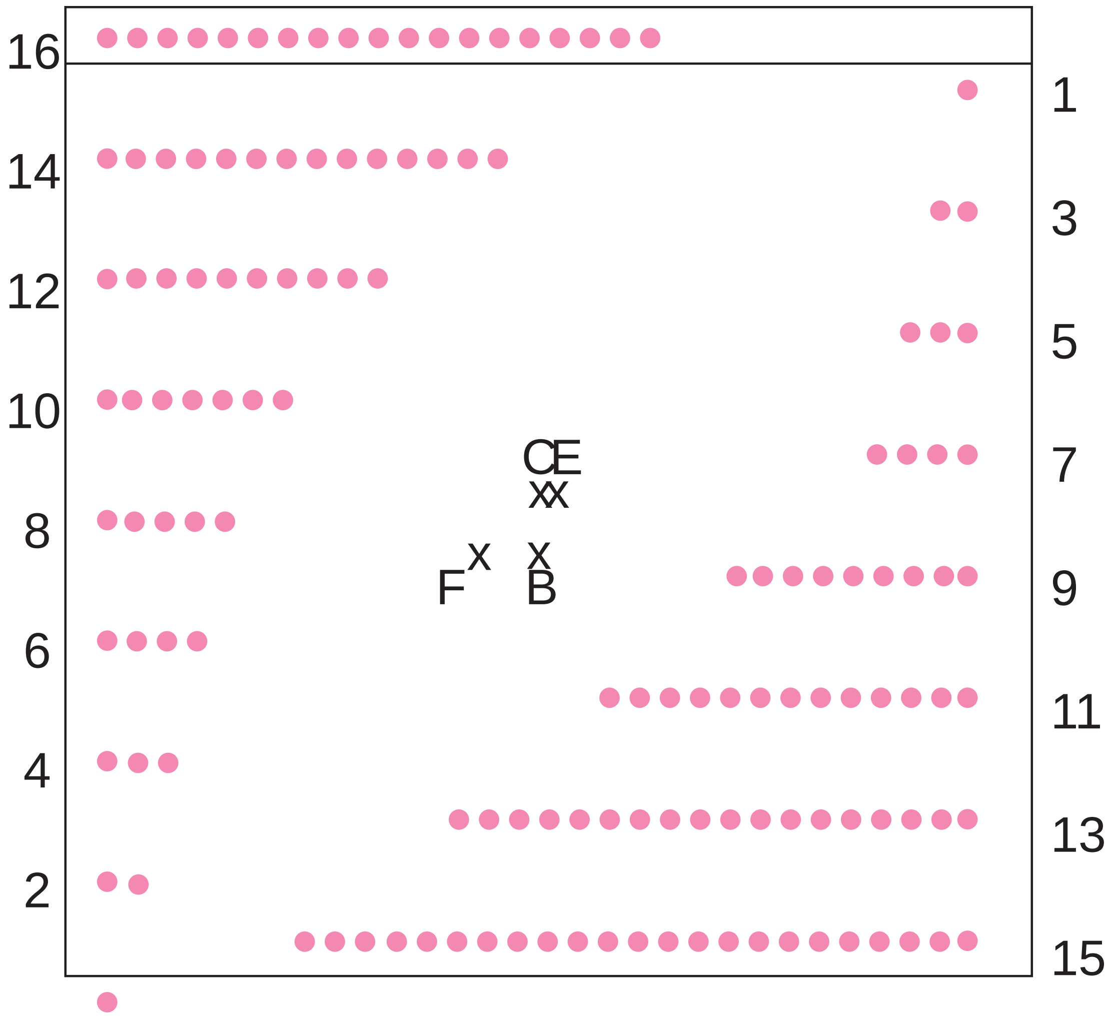
# The bad news

- Losses would eat you alive for 91 bounces
  - » (Some say MEM's will improve- down to 0.1 dB/bounce- then could do this in a 10 dB loss budget)
  - » Guess what- that's still too high

# But…

- Let Mirror F shift by several spots
- Now E is fine control
  - » F is coarse control
- Can get more outputs for same number of bounces
- Need fewer pixels, too

# Spot pattern



# Improvement

- Before 16 bounces=9 outputs
- Now 16 bounces=23 outputs
- Goes as number of bounces squared
  - » Call it the “quadratic cell”
- Improvement increases rapidly as bounce number increases

# Number of outputs:

$$N = \left(\frac{m}{4}\right)^2 + 2\left(\frac{m}{4}\right) - 1$$

- Now to get at least 91 outputs need only 40 bounces (produces 119 outputs)
- But still not good enough

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# Just suppose…

- Suppose a micromirror could tip to *three* different positions rather than two
- Can add two more spherical mirrors
- Now number of outputs goes as $m^4$
- Now can get 254 outputs in 12 bounces
  623 outputs in 16 bounce

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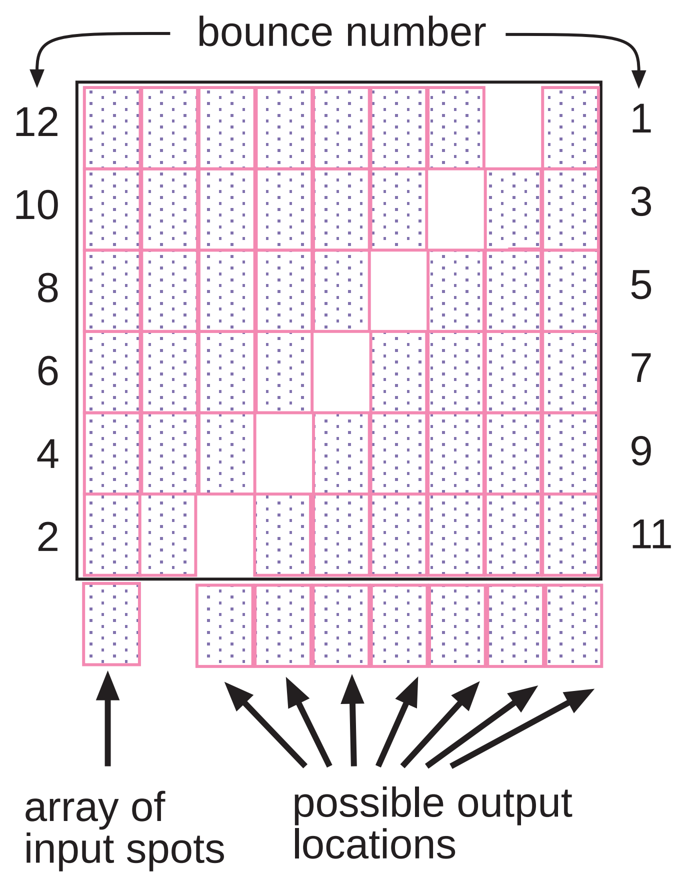
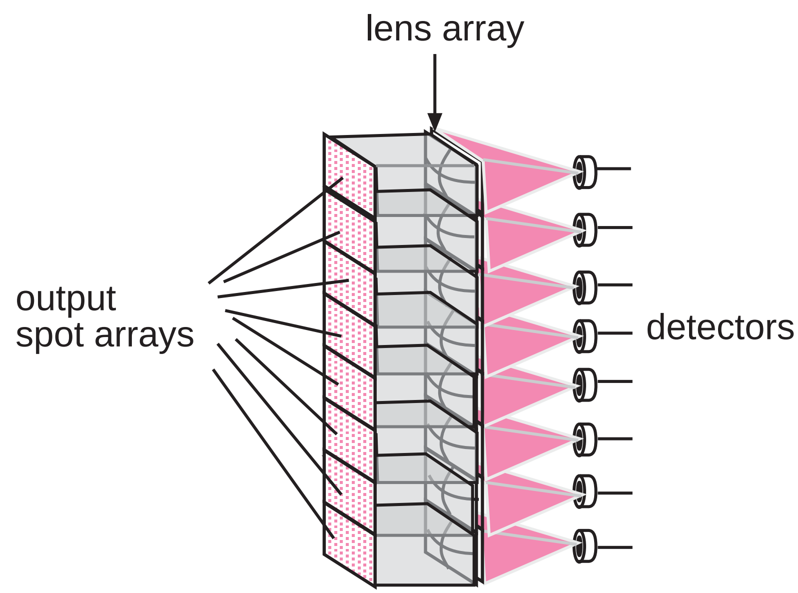
# How to handle multiple inputs?

- Input region can contain an array of spots
- Each beam has a unique bounce pattern
- Each beam can be independently controlled



# To connect to outputs:

- Lens array
- Focus each output region to a detector (or fiber)
- Any spot landing in that region goes to correct fiber (or detector)
- We have other approaches for going into fiber…

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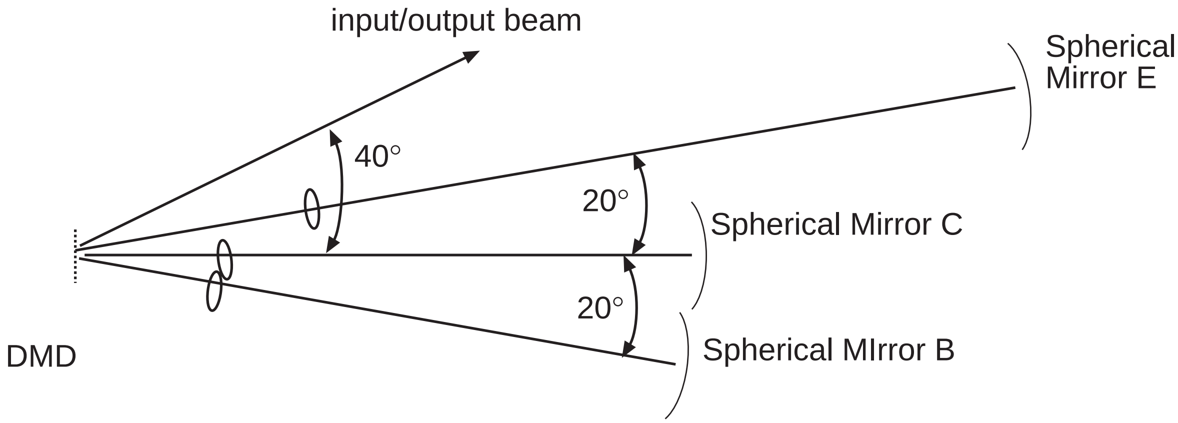
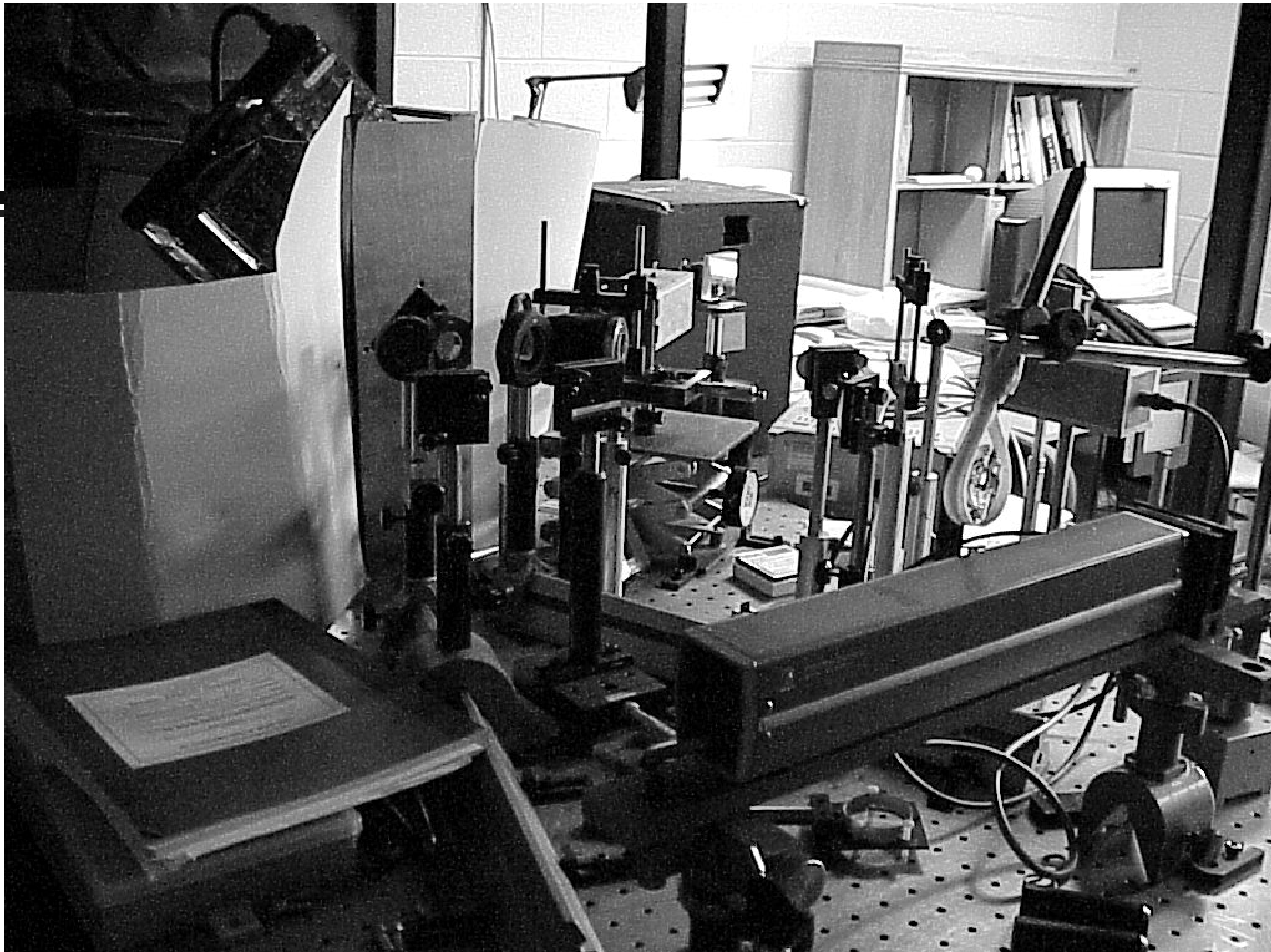
# Laboratory apparatus

- Couldn't get a DMD so used a projector
- Used groups of pixels as "macropixels" (50x50) to keep spot sizes tractable
- HeNe laser as source
- CCD camera to monitor output position change
- Demonstrated 8 bounces and 4 outputs

# Top view

- Unfunded research: use old parts from closet
- Not all mirrors have same focal length
- Doesn't affect spot pattern





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# Key feature:

- Number of connections depends on number of pixels on MEM
- 768x1048 arrays currently available for projectors-that makes for massive parallelism
- Can use hybrid arrays (multiple MEM’s on a board) for even more capacity

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# Benefits:

- Ours has built-in redundancy- if some mirrors fail, who cares?
  - » Lots of ways to get to a given output
- Easy to scale up
- Won't need constant calibration

# Where we are now

- Have demonstrated very similar devices for unrelated project- no show-stoppers yet and none expected
- Did a simple temporary demo in lab of interconnect- (one input, four outputs) on borrowed equipment from other project (it worked)
- Measured output losses- same as for Lucent-style switch

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# Summary

- Optical Interconnection based on the White cell
- Simple (dead simple) optics
- Low component count (one switch for lots of inputs and outputs)
- Easy to scale up
- Demonstrated proof-of-concept in the lab

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