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ADRIATICO CONFERENCE ON FOURIER OPTICS AND HOLOGRAPHY

OPTICAL COMPUTING

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OPTICAL COMPUTING

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INTRODUCTION

ANALOG OPTICAL COMPUTING HAS A LONG TRADITION; QUITE USEFUL, BUT MOSTLY AD HOC ⟨1⟩*

HERE WE CONCENTRATE ON BINARY SIGNALS ⟨2⟩

WHY SHOULD OPTICS GET INVOLVED?

THERE SEEMS TO BE A SLOWDOWN IN PROGRESS OF SUPERCOMPUTERS.
HENCE MANY OF SMALLER PROCESSORS COUPLED TOGETHER → COMMUNICATIONS PROBLEM ⟨3⟩

WORTHWILE? YES, ESPECIALLY FOR GLOBALLY STRUCTURED ALGORITHMS ⟨4⟩

FUNDAMENTALS

ELECTRONS DO INTERACT → LOGIC GATES
PHOTONS DO NOT INTERACT → COMMUNICATION ⟨5⟩
BUT PHOTONS IN NONLINEAR MEDIA DO INTERACT

FREE SPACE OPTICS IN 3D EXCELLENT FOR DATA TRANSPORT, NOT GUIDE-BOUNDED ⟨6⟩

MANY WAYS TO DO OPTICAL LOGIC
FOR EXAMPLE LIKE ICHIOKA's OPALS ⟨7⟩

* NUMBERS IN BRACKETS LIKE ⟨1⟩ REFER TO FIGURES
THE LATEST SURVEY: "DIGITAL OPTICS", to appear in PROC. IEEE, early 1990

OPTICAL ARCHITECTURES COULD BE STRUCTURED IN MANY WAYS,
FOR EXAMPLE AS PIPELINES ⟨8⟩ OR AS LOOP ⟨9⟩

A CRUCIAL PART OF EVERY PARALELL MULTIPROCESSOR IS A COMMUNICATIONS NETWORK, CALLED „SWITCHYARD" IN ⟨9⟩
A SIMPLE CASE IS A „CYCLIC SHIFTER" ⟨10⟩.

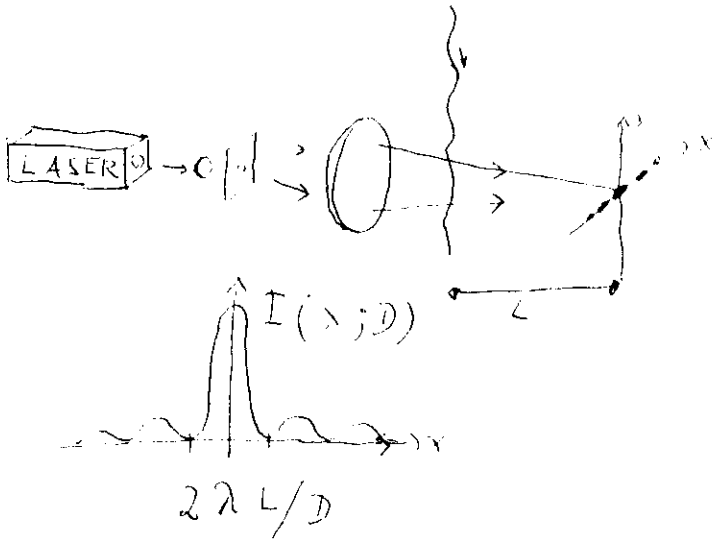
THE GENERAL CASE OF A NETWORK WITH N ENTRANCES AND N EXITS CAN BE OF THE CROSSBAR-VARIETY (WITH N^2 SWITCHES) OR OF THE $N \log N$-VARIETY, SUCH AS THE OMEGA-NETWORK, WHICH CONTAINS PERFECT SHUFFLES ⟨11, 12, 13, 14⟩.

A HYBRID SYSTEM WITH OPTICAL CONNECTIONS AND ELECTRONIC LOGIC IS PERHAPS A REASONABLE GOAL.
SEVERAL FEATURES ARE CRITICAL ⟨15⟩.
THE STYLE OF OPTICAL INSTRUMENTION HAS TO BE CHANGED („PACKAGING" ⟨16⟩).
RELATIVE COSTS HAVE TO BE CONSIDERED IN VIEW THE VARIOUS REASONS FOR OPTICAL COMPUTING ⟨17⟩.

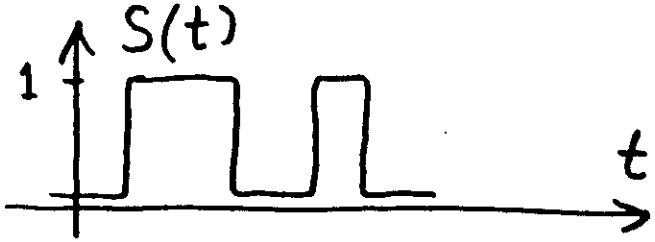
OPTICAL ANALOG COMPUTERS

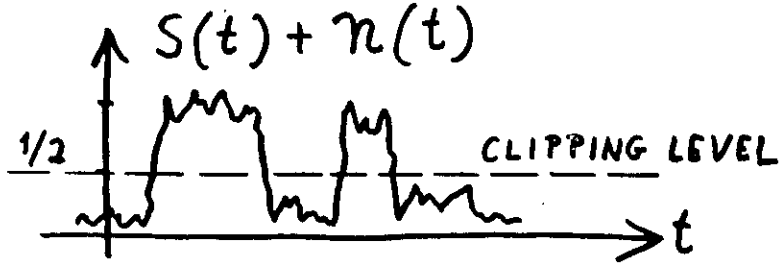
OFTEN QUITE USEFULL
BUT MOSTLY FOR SPECIAL PURPOSES

MEASURING THE THICKNESS
OF A MOVING THREAD, WHICH JITTERS



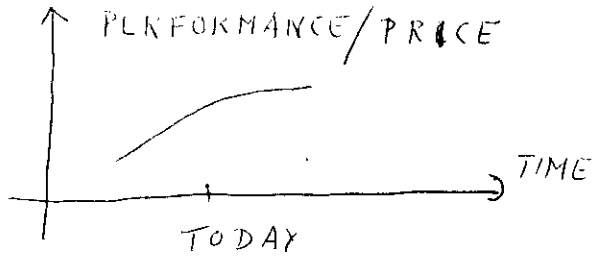
ERROR INSENSITIVITY OF BINARY SIGNALS





ERROR $\frac{1}{2} S_{MAX}$ TOLERABLE

CRISIS OF SUPER COMPUTERS



FASTER HARDWARE ?
(Si → GaAs ~ x10)

HENCE PARALLEL

FEW BIGs

MANY SMALLS

CARTESIAN NET
(ONLY NEAREST NEIGHBORS)

GLOBAL NET
TRAVEL TIME
$\leq \log$ (DISTANCE)

GLOBAL CONNECTIONS NEEDED ?

YES, FOR EXAMPLE FOURIER

$$\tilde{u}(m) = \sum_{n=0}^{N-1} u(n)\, e^{2\pi i\, m n / N}$$

far reaching

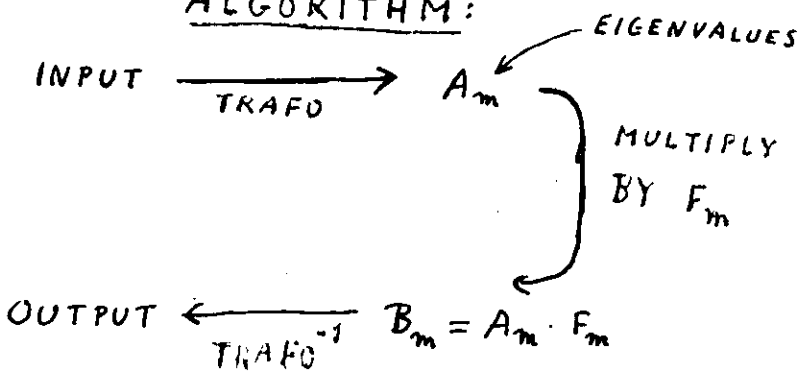
IN $2 \log N$ steps, N-fold parallel

YES, USEFUL FOR EVERY LINEAR SYSTEM

$$\text{INPUT}(x) = \sum_{(m)} A_m \cdot \text{EIGENFUNCTION}_m(x)$$

$$\text{OUTPUT}(x) = \sum B_m \text{ EIGENFUNCTION}_m(x)$$

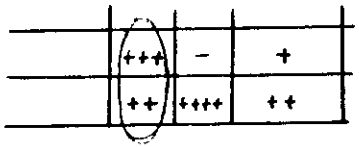
ALGORITHM:



ELECTRONS OR PHOTONS
ELEKTRONEN ODER PHOTONEN ?

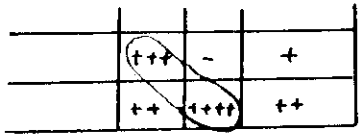
	⊖ ⊖	Δ Δ	EXOTISCHE MATERIE Δ Δ ⟹ Δ
LOGIK Wechselwirkung	+++	−	+
TRANSPORT Kommunikation	++	++++	++

HEUTE



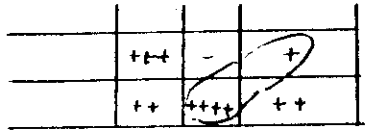
TODAY

MORGEN



TOMORROW

ÜBERMORGEN



THE DAY AFTER TOMORROW

THE BEAUTY OF FREE SPACE OPTICS

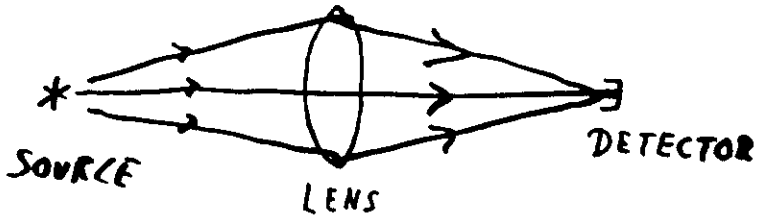
NO ABSORPTION

NO DISPERSION (WITH ACHROMATIC OR APO-CHROMATIC LENSES)

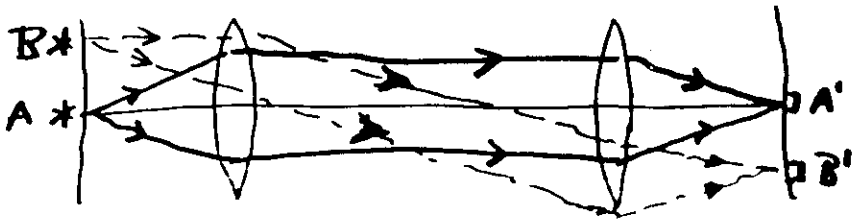
FULL SPEED 30 cm / n sec

NO IMPEDANCE MATCHING PROBLEMS (AS IN BACKPLANE HEATERS)

PHANTASTIC SYNCHRONISATION $\pm 10^{-15}$ Sec



SYNCHRONISATION IN PARALLEL

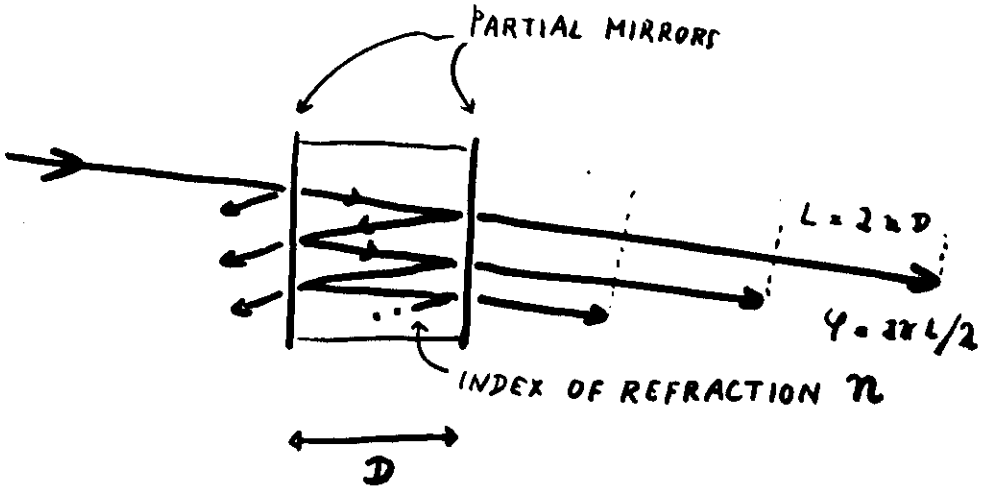


$$\Delta t_{AA'} - \Delta t_{BB'} \leq 10^{-15} \text{ sec}$$

1000 x 1000 PIXELS IN PARALLEL

FABRY-PEROT INTERFEROMETER

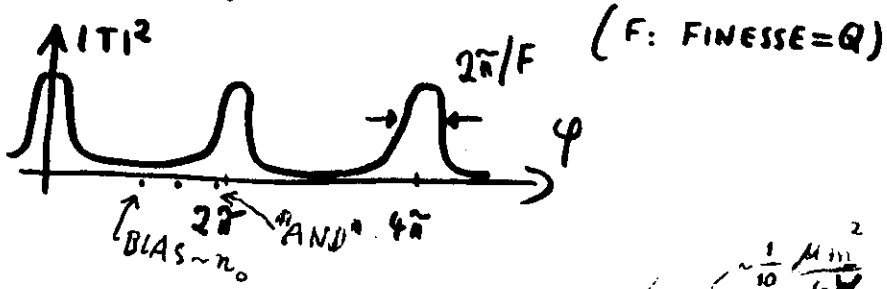
AS LOGIC GATE



AMPLITUDE TRANSMISSION T = fct(n)

$$T \sim \sum_{m=0}^{\infty} (Ae^{i\varphi})^m = \frac{1}{1-Ae^{i\varphi}}$$

(½π) $\varphi = 2Dn/\lambda$ $\quad \varphi = \frac{2\pi}{\lambda} \cdot 2nd$



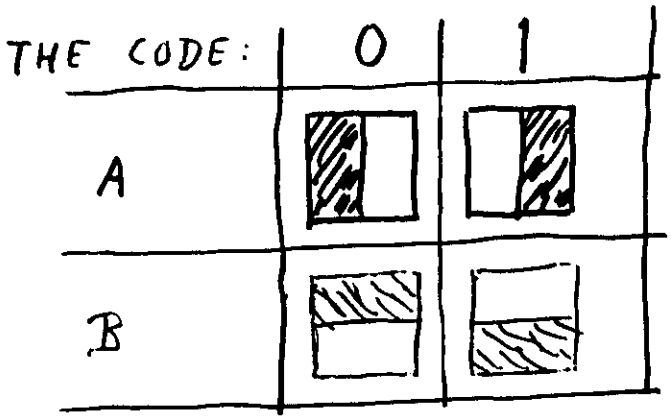
(F: FINESSE = Q)

$n = fct(\text{radiant energy}) = n_0 + n_2 \cdot I_{INSIDE}$ $\quad \sim \frac{1}{10} \frac{Mm^2}{\mu W}$

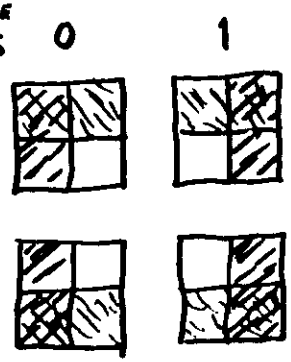
OPAL

OPTICAL PARALLEL LOGIC

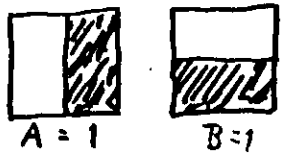
Y. ICHIOKA, OSAKA



MULTIPLICATIVE SUPERPOSITIONS

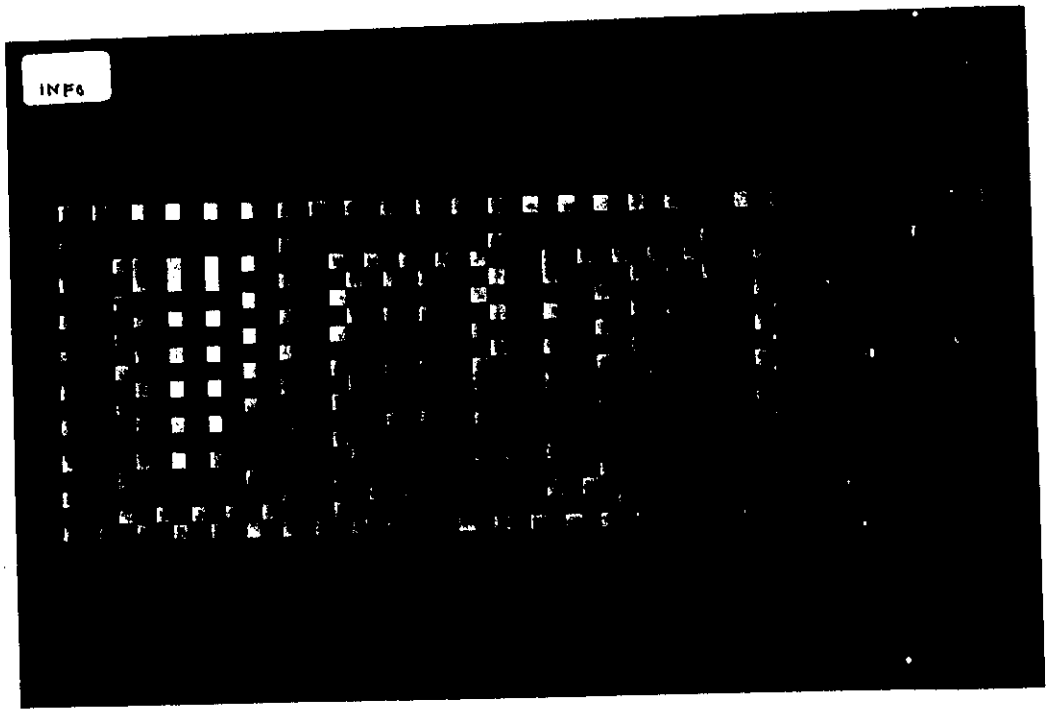


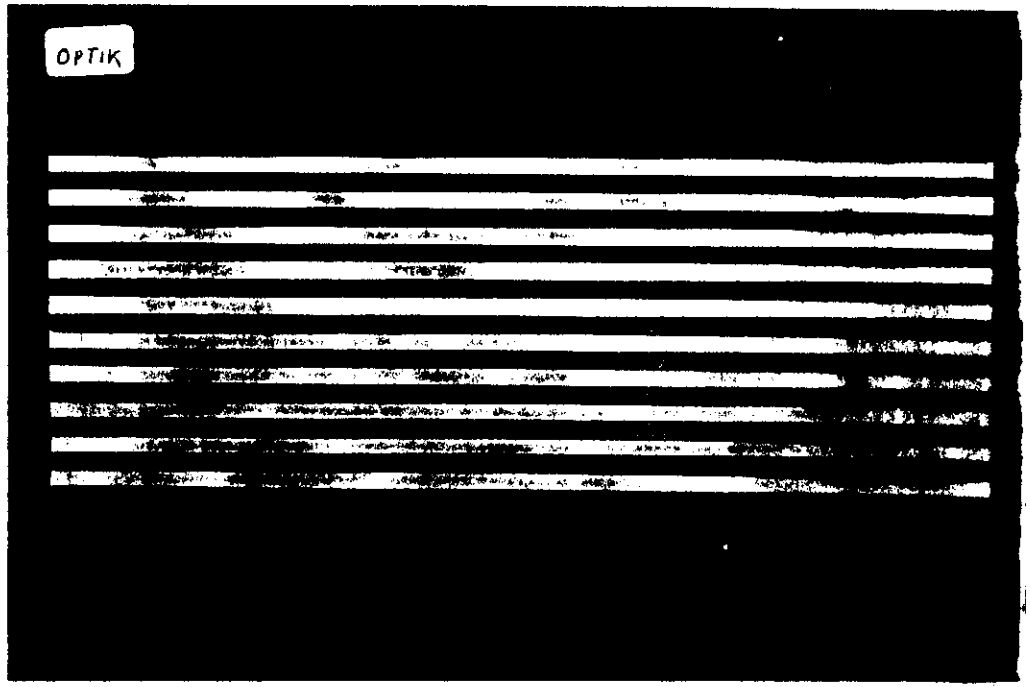
DECODING MASKS

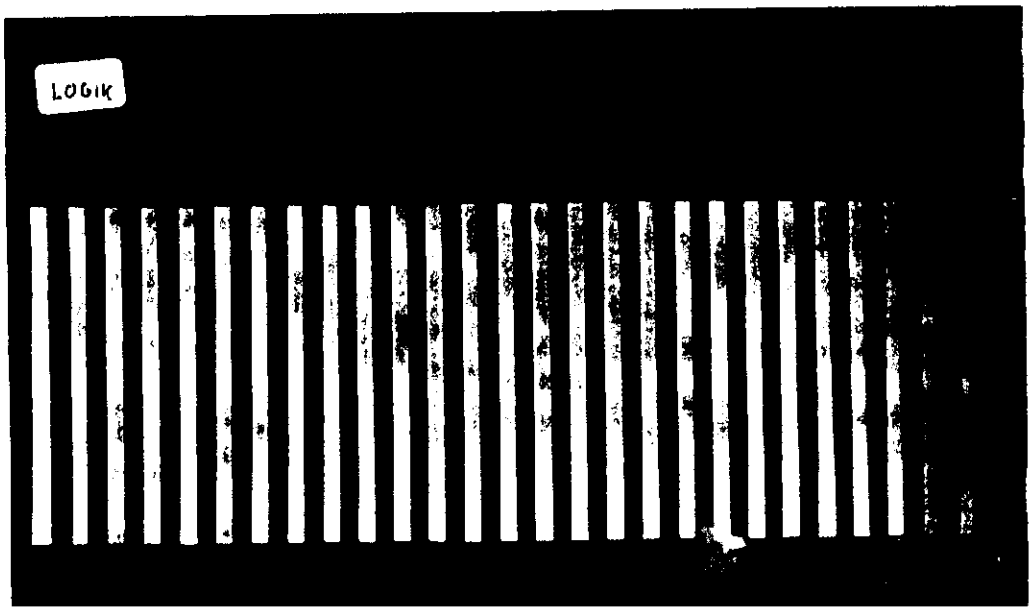


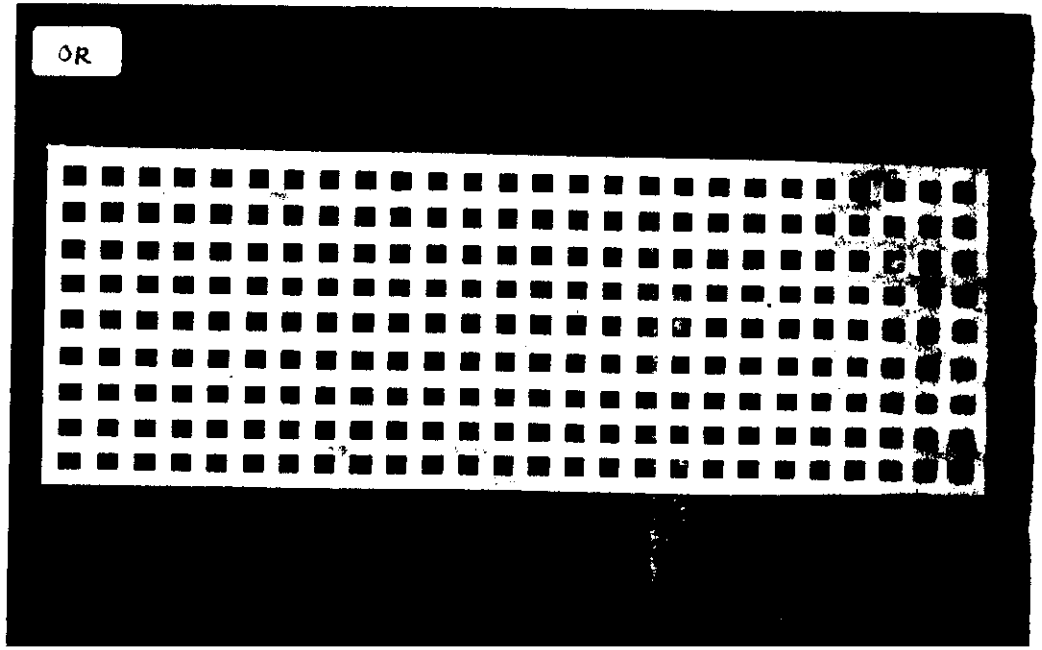
LOGIC MASKS

A(x,y) ON TOP OF B(x,y)





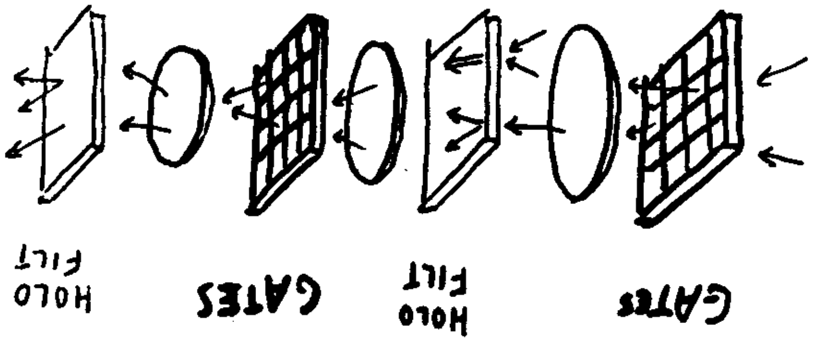




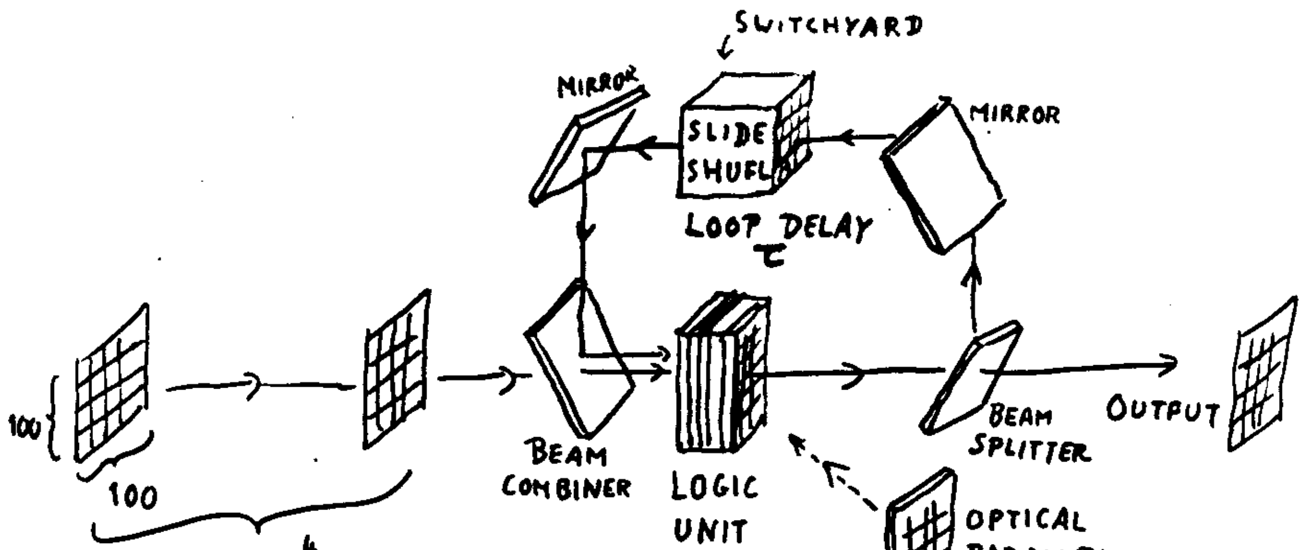
CONCEPTUAL SETUP

PIPE LINE

ALTERNATING:
GATE ARRAYS INTERCONNECTS



CONFIGURATION OF A DIGITAL OPTICAL PARALLEL PROCESSOR



INPUT : 10^4 PIXEL ARRAY

AT A RATE $\sim 1/\tau$; $\tau = 10^{-9}$ sec

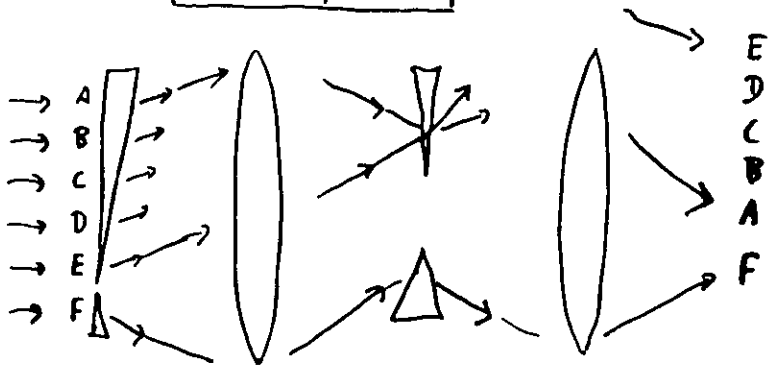
$c \cdot \tau = 30$ cm

10^{13} OPS

NASA (1995) SPECS: 10^6 INPUT, $\tau = 10^{-8}$ sec

CYCLIC SHIFTING

INPUT	A	B	C	D	E	F	
ORDINARY SHIFT		A	B	C	D	E	F
CYCLIC	F	A	B	C	D	E	



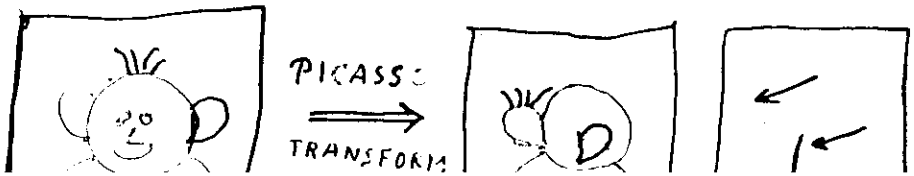
N inputs

PUPIL SHARING
(here M = 2)

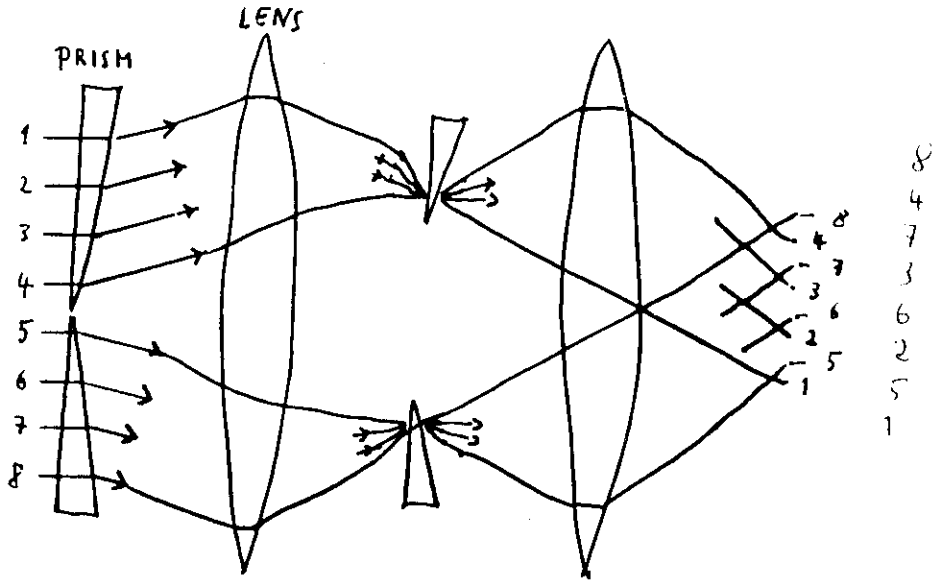
A SPACE-VARIANT SYSTEM

PIECE-WISE INVARIANT (M PIECES)

$$N \times M \leq SW$$



OPTICAL IMPLEMENTATION of the PERFECT SHUFFLE

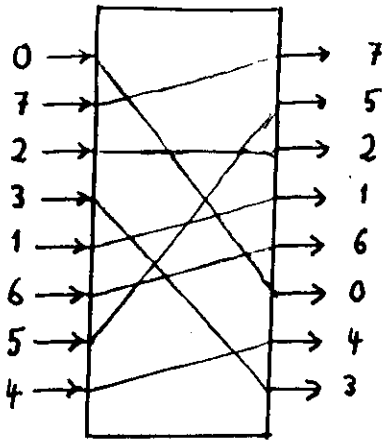


„hardwired" part of one stage of an

(N = 8) – PS

OMEGA NETWORK

FOR ARBITRARY PERMUTATIONS



here

$N = 8 = 2^3$

$\log N = 3$

OMEGA consists of

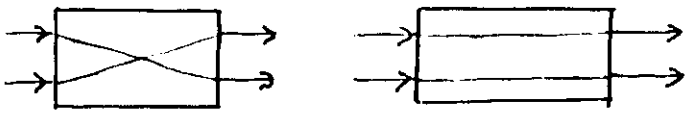
(3) $\log N$ identical LAYERS.

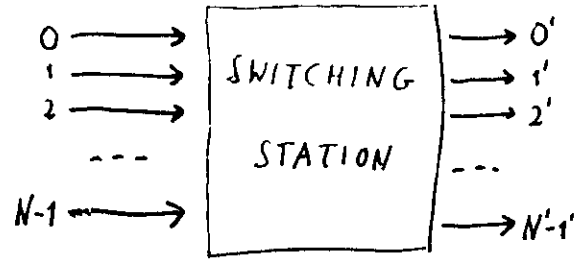
A LAYER consists of

a ("hardwired") PERFECT SHUFFLE

and of $N/2$ special 4-ports:

EXCHANGE - OR - BYPASS

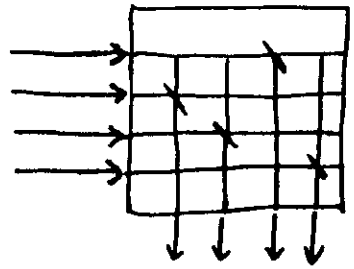




$N!$ CONCEIVABLE PERMUTATIONS

HENCE $\log_2(N!)$ BINARY SWITCHES NEEDED

$\sim N \log N$



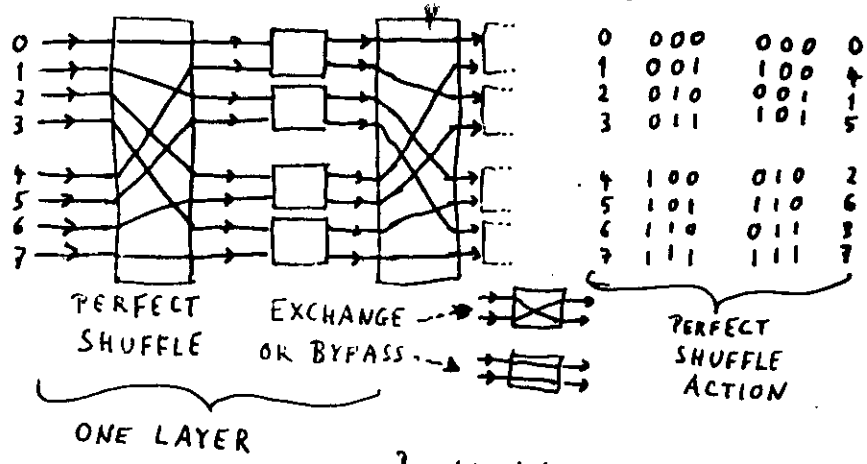
CROSSBAR

N^2 BINARY SWITCHES

N: 

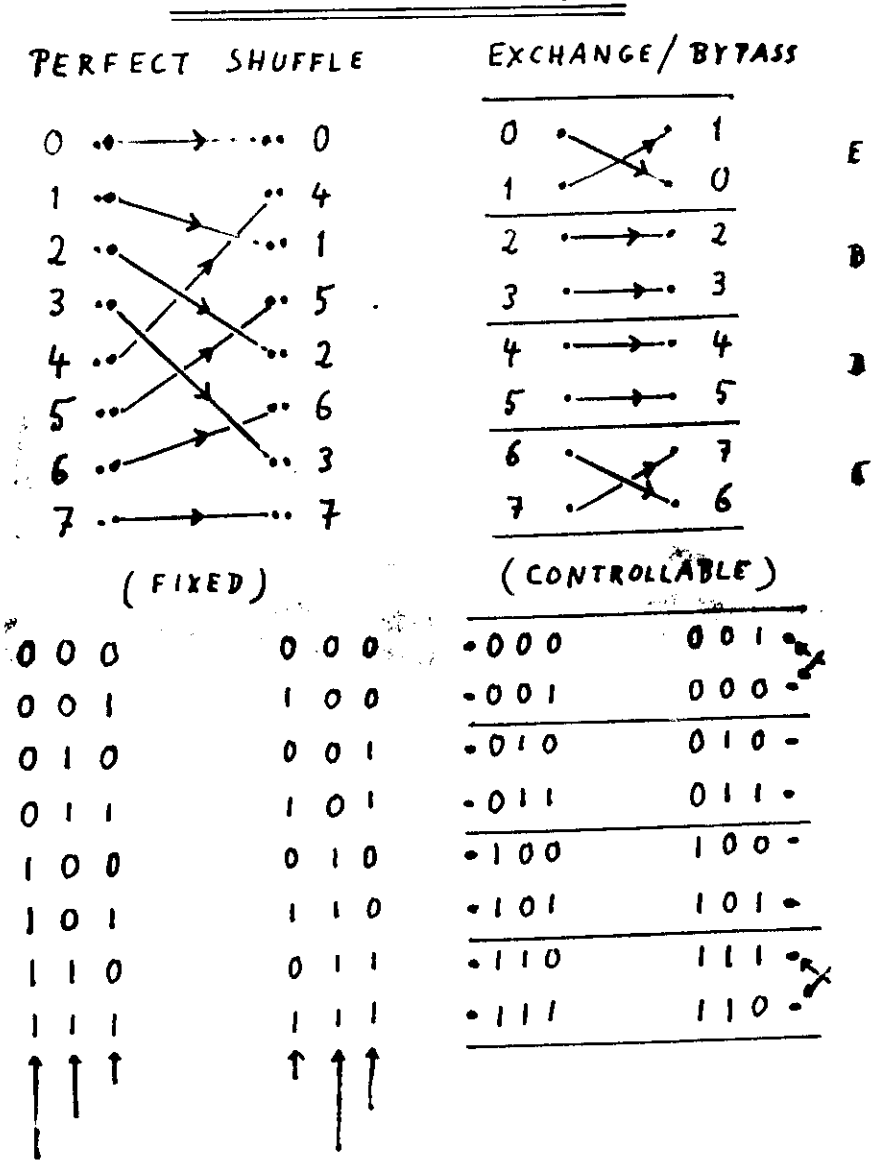
N^2-N: 

OMEGA Network $\sim 3N \log N$ binary switches



$\sim \log N$ LAYERS NEEDED

DATA SWITCHYARD



EVERY PERMUTATION OF ADDRESSES

IN NOT MORE THAN $3 \log N + 1$ STEPS

SOME DESIRABLE FEATURES

OF NONLINEAR OPTICAL ELEMENTS

SPEED $\geq$ ELECTRONICS

FAN-IN, FAN-OUT, SENSITIVITY

HEAT DISSIPATION

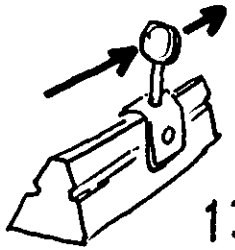
3-PORT (NOT THRESHOLD LOGIC)

MANUFACTURABLE

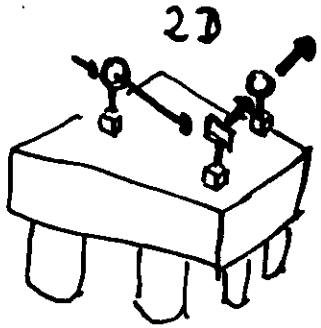
AS ARRAY, RELIABLE, CHEAP

4 GENERATIONS

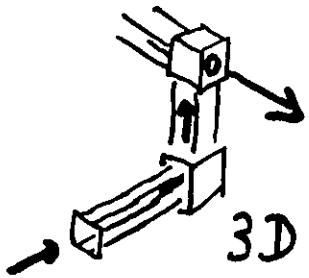
OF OPTICAL SETUPS



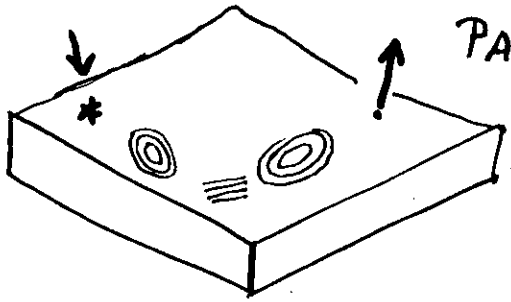
1D



2D



3D



FOLDED ; LITHOGR. DIFFRACT. COMPONENTS ;

A-THERMAL PLANE PARALLEL QUARTZ ; MIRRORS BELOW.

COMPUTING =

$$= \left\{ \begin{array}{c} (\text{LOGIC})\ \text{PROCESSING} \\ \\ \text{COMMUNICATING} \end{array} \right\} \text{OF SIGNALS}$$

RELATIVE COSTS IN ELECTRONICS

PROCESSING	COSTS	COMMUNICATION
TUBES	$>>>$	WIRES
TRANSISTORS	$>>$	WIRES
IC TRANSISTORS	$\approx$	PLANAR GUIDES
IC TRANSISTORS	$<<$	MULTI-PLANAR GUIDES

5 4 REASONS

FOR COMPUTING OPTICALLY

(1) HIGHLY PARALLEL COMMUNICATION

(2) FASTER PROCESSING

(3) EMI / EMP HARDENED

(4) SPECIAL SUBSYSTEMS : ROM, BUS, ASSOC. M., ... SHUFFLE, DISPLAY

(5) NEURAL COMP. / ASSOC. , WORM