Signal and Image Processing: Analog, Digital, and Everything In-Between

Electrical Engineering Pioneer Talk

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USC Engineering

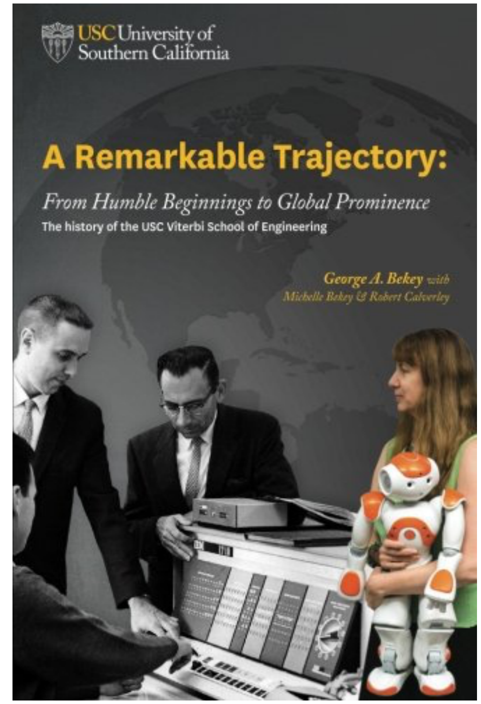
- *A Remarkable Trajectory* – George Bekey

- Zohrab Kaprielian: Dean, Provost, Executive Vice-President

- Communications faculty - Magnificent 7
  - Solomon Golomb
  - Robert Scholtz
  - Lloyd Welch
  - William Lindsey
  - Robert Gagliardi
  - Charles Weber
  - Irving Reed

- Lasers, photonics faculty
  - Robert Hellwarth
  - William Steier
  - Sergio Porto

Controls faculty
- George Bekey
- Len Silverman
- Nasser Nahi



Education

- June 1966 - MIT BS EE - thesis - Tom Huang - image compression
- Summer 1966 - NASA Goddard - free-space optical communications
- Summer 1967 - Communications Satellite Corporation (Comsat)
  - Reducing intersymbol interference in digital communications
  - April 1967 Viterbi algorithm paper
- June 1968 - Stanford MS EE
- April 1972 - Stanford PhD EE
  - Modeling imaging systems
  - Digital image restoration and enhancement

Signal and Image Processing at USC

- Late 1960s
- Bill Pratt, Harry Andrews
- Irving Reed, Lloyd Welch
- Transform image coding – JPEG, MPEG, .jpg, .mp3., mp4, etc.

- Late 1970 ARPA contract ($2.1m for 3 years - $13.2m today)
- Arpanet connection
- Image input devices – scanners
- Output devices – display
- Computing - IBM 360/44, HP 2100, DEC PDP11

- USC Image Processing Institute (IPI) - 1972

- December 1971 – I arrived at USC

Olin Hall – December 1971

Muirhead Analog Scanner

Scott Minium, Bill Pratt

Image Scanning Hardware

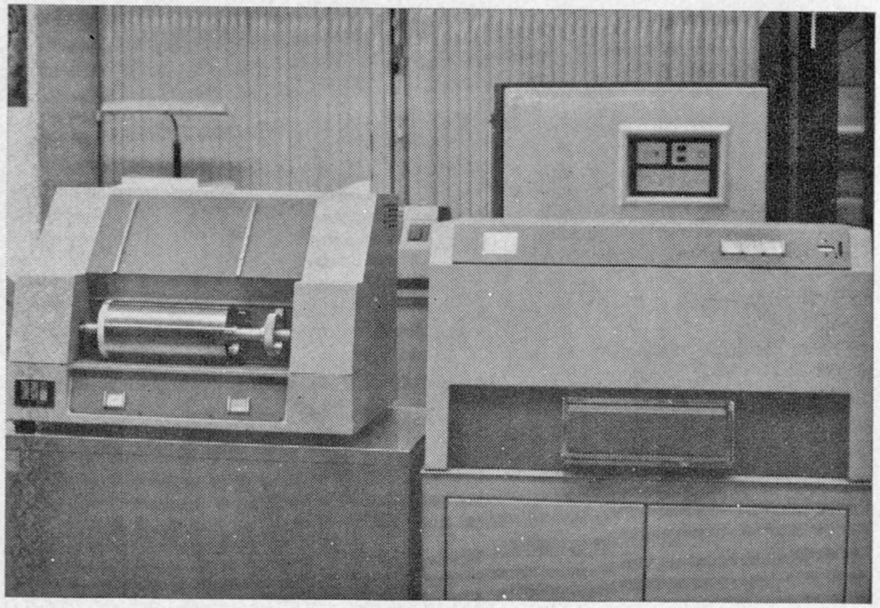


Figure 5. Electromechanical color facsimile system.

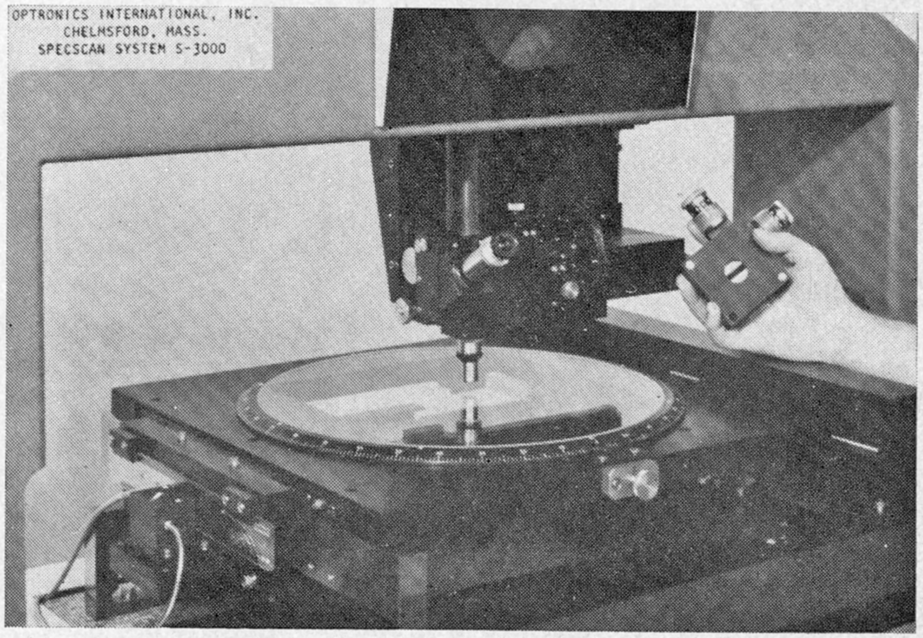
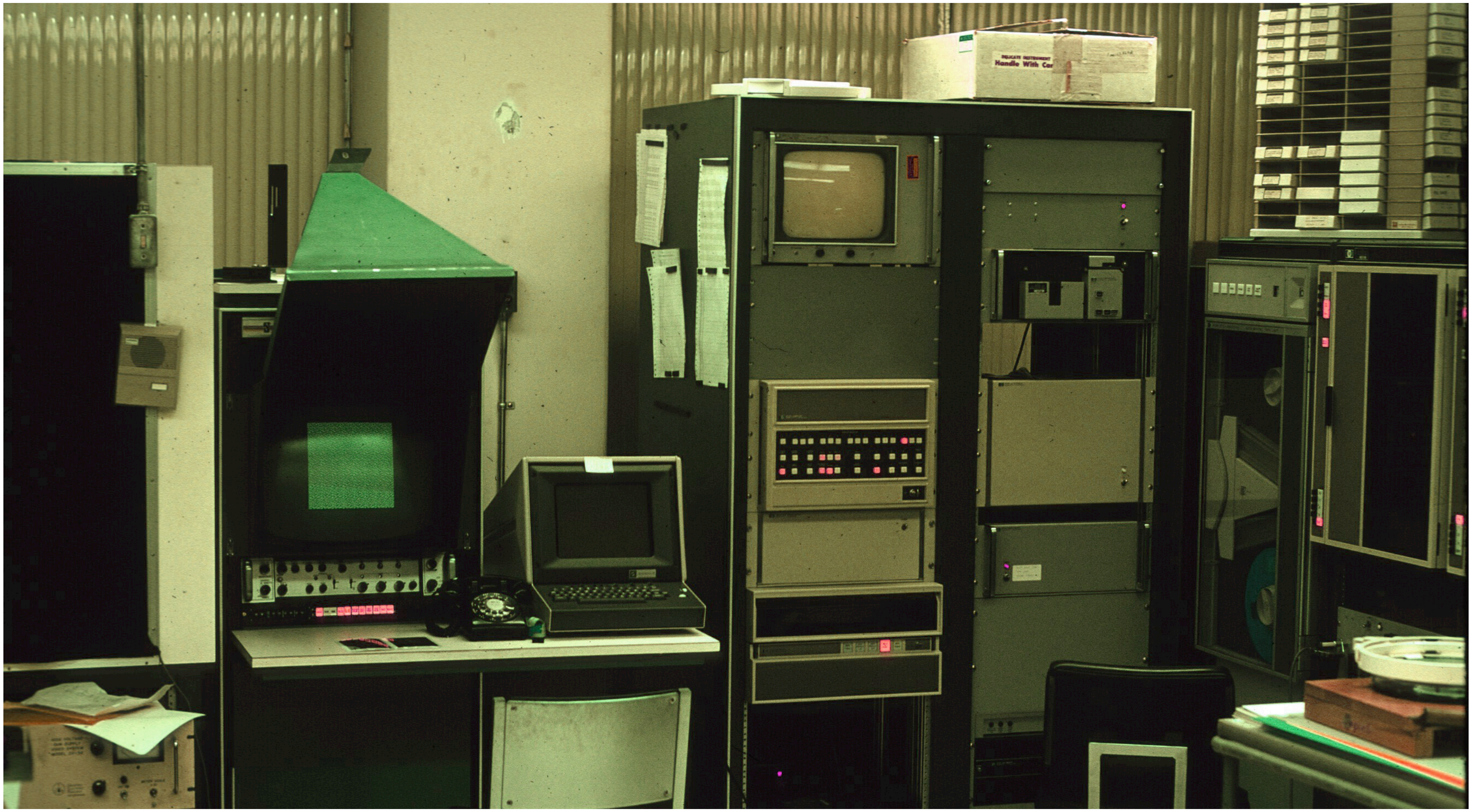


Figure 7. Flat bed scanning microdensitometer.

IPI Lab – December 1971



ARPANET

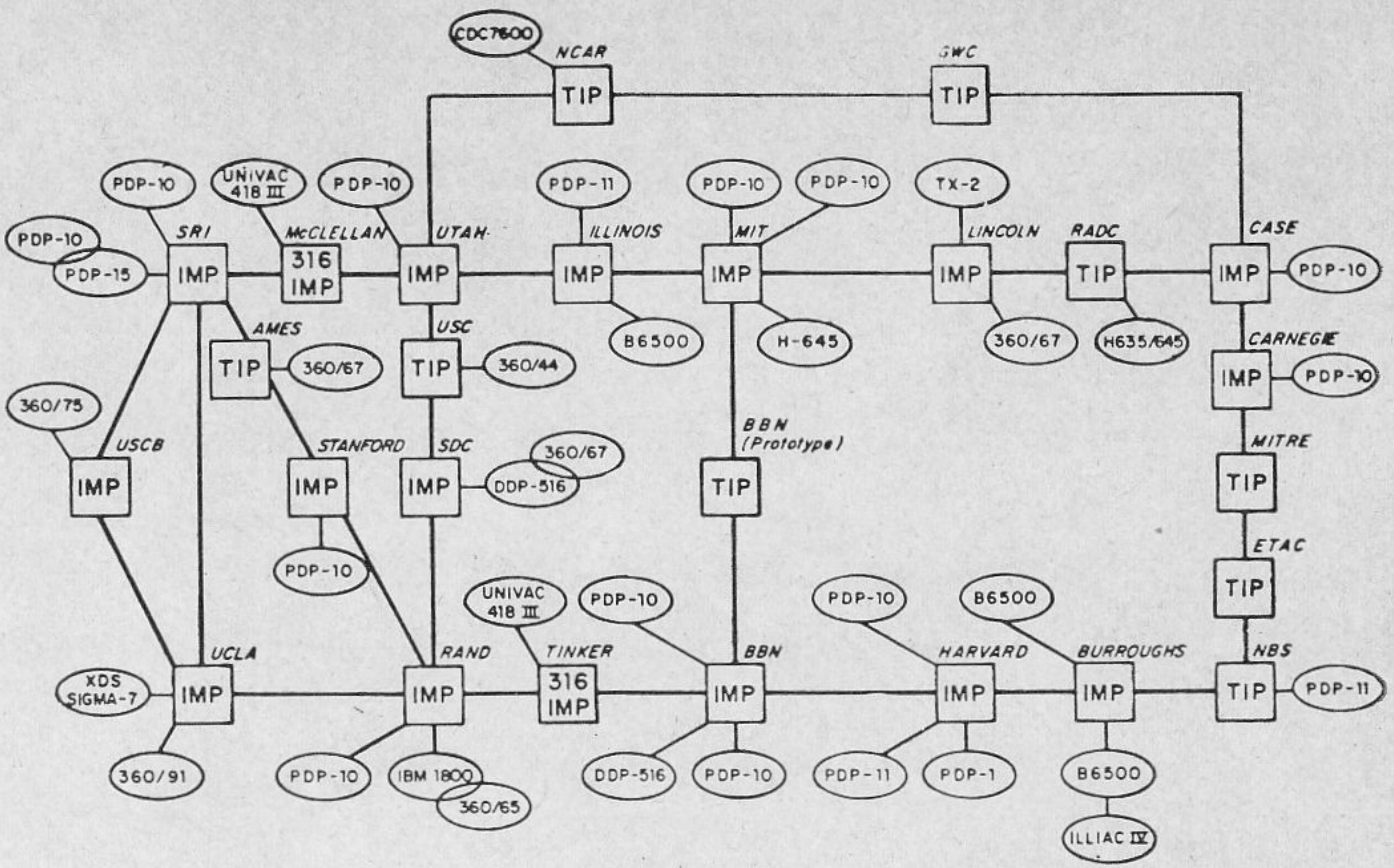
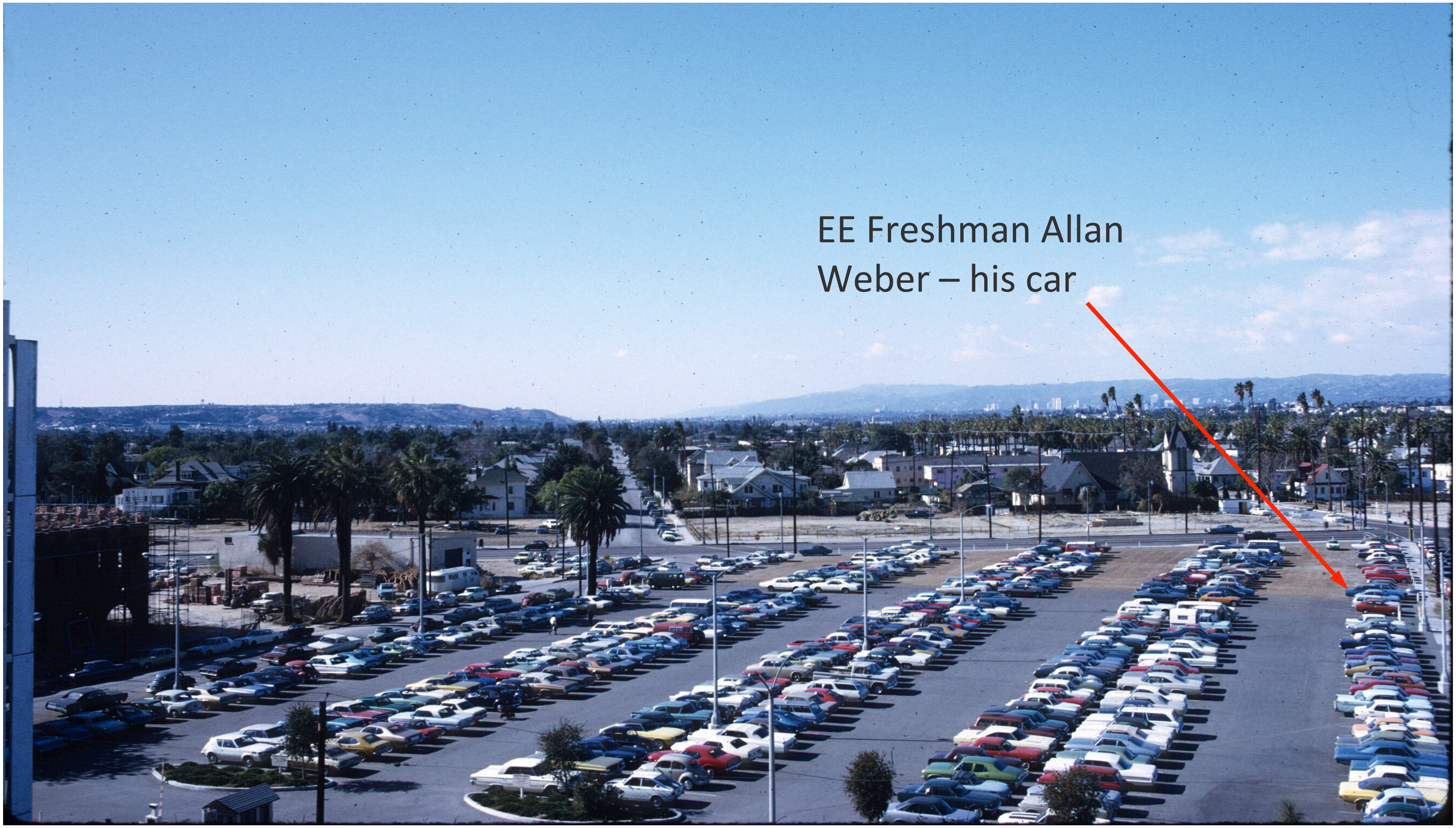


Figure 9. ARPA Net, mid-1927

USC - December 1971

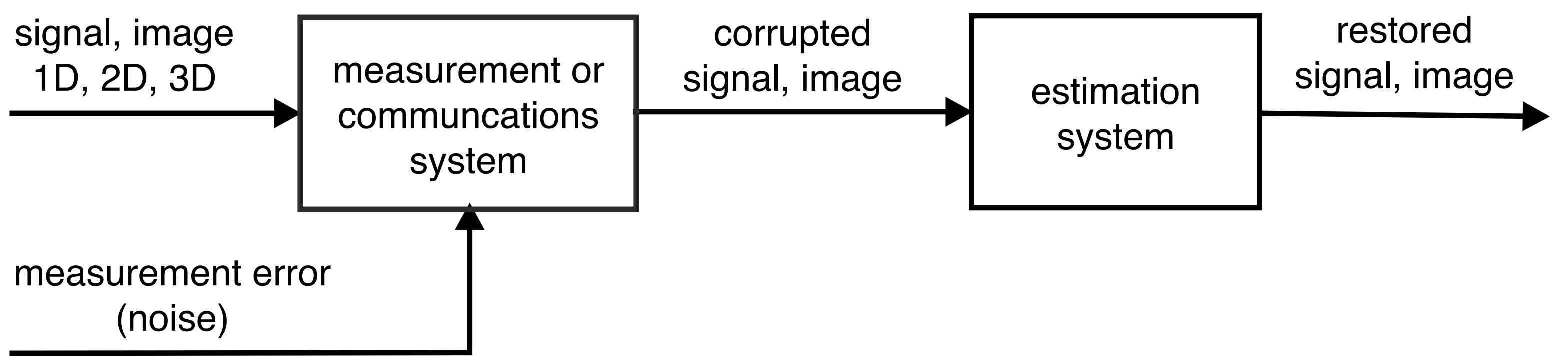
Looking North from Olin Hall-December 1971

Looking West from Olin Hall December 1971



Signal Processing For Computation-Intensive Tasks

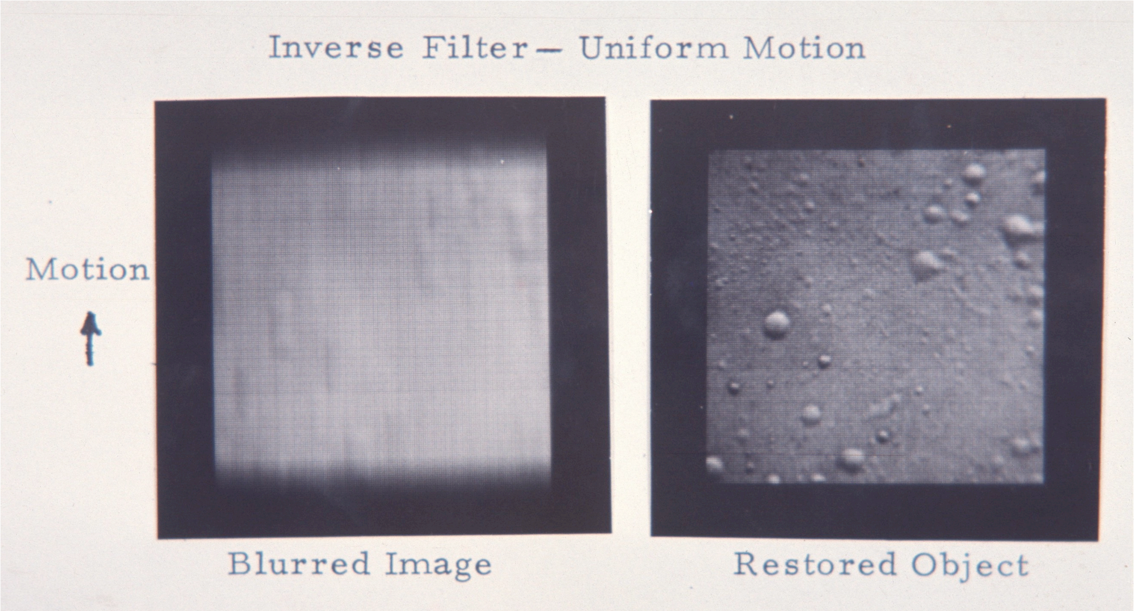
- **Images, video**
- Analog - continuous values – the real world
- Digital - discrete



- **General Image Restoration Models - Inverse problem**
  - signal (image) 1D, 2D, 3D (models)
  - measurement system (models: linear, nonlinear, time varying, space-variant, known, unknown, partially known)
  - measurement error (noise, additive, multiplicative, signal dependent, Poisson, etc.)

Image Restoration

- Estimate the original image



- Film-grain, detector noise
- Speckle noise in coherent imaging – synthetic aperture radar, laser illuminated images
- Criteria: human observer; mean-square error, MAP, ML, model-fitting, etc.

Restoration – Speckle Noise

- Speckle noise from coherent illumination – synthetic aperture radar, laser

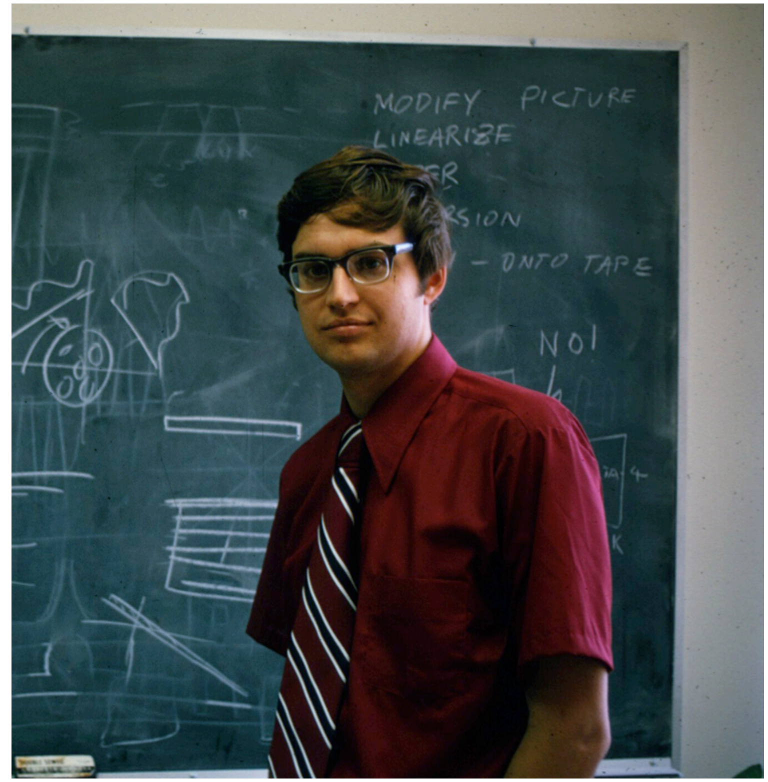
original

original with speckle noise

processed result

Darwin Kuan, C.-M. Lo

Powell Hall Dedication - 1973



SIPI Image Database - 1

- 1960s – 1970s
- Usual image processing test images – NTSC

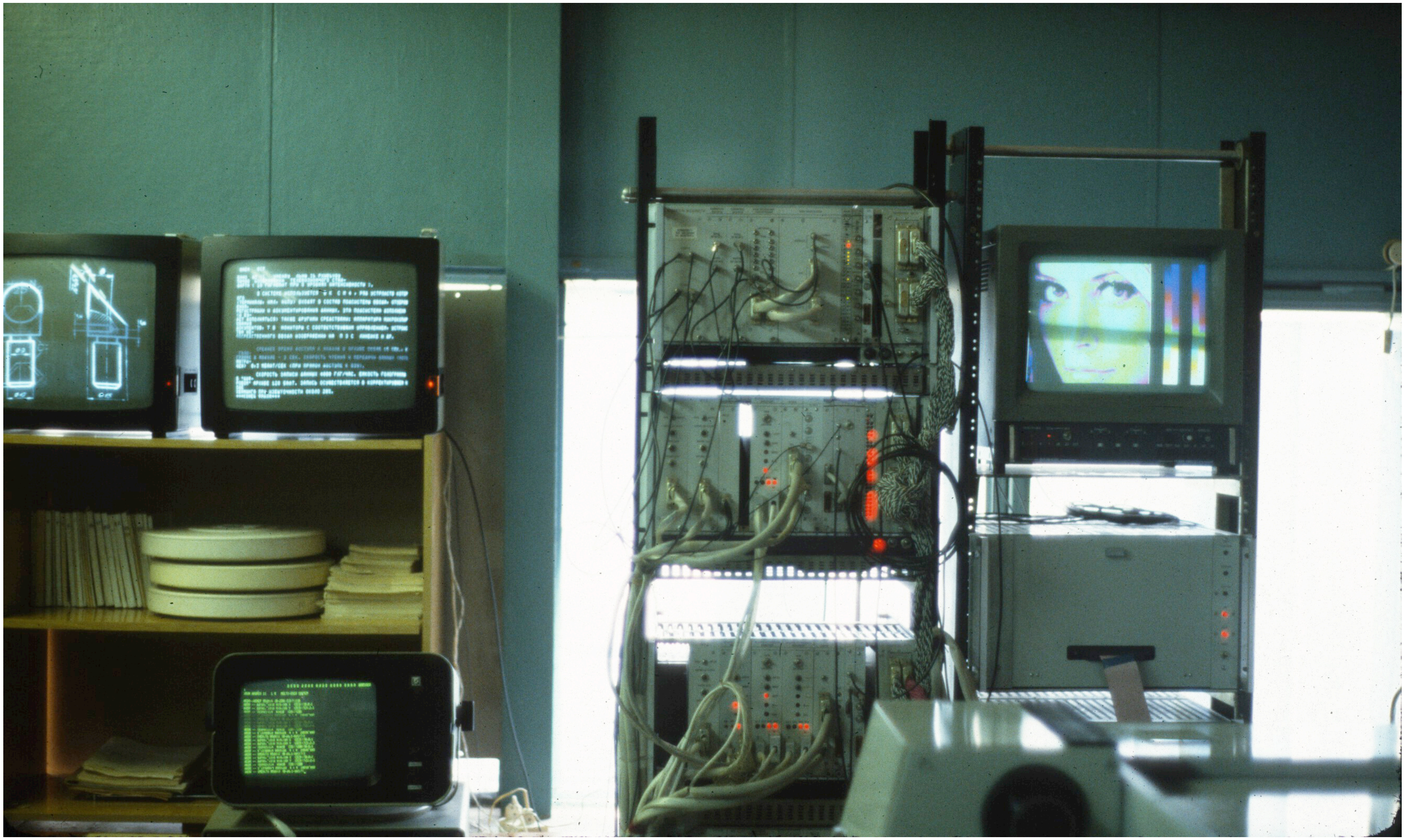
SIPI Image Database - 2

- 1970s

Lena - Lenna

- 1973 scan of Lenna (real name Lena Sjööblom (now Lena Söderberg)
- 5.12 x 5.12 inches – lines 1 and 2 are identical!

Akademgorodok – Novosibirsk, Siberia, USSR - 1986



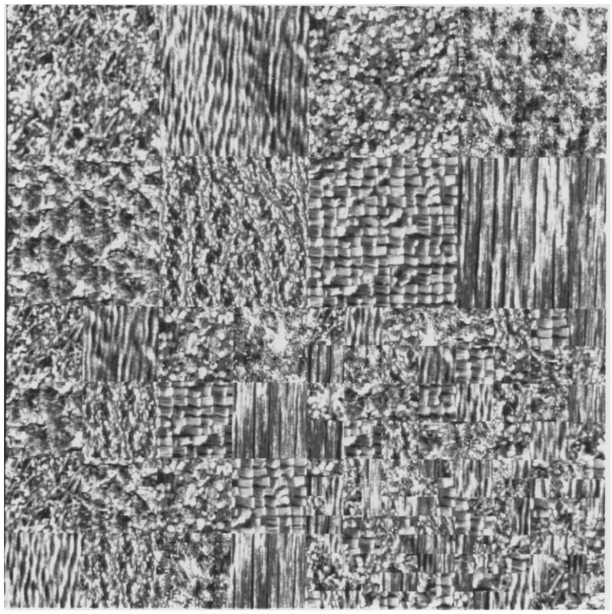
"no image has been more important in the history of imaging and electronic communications' -- CMU School of Computer Science

Lena - 1997

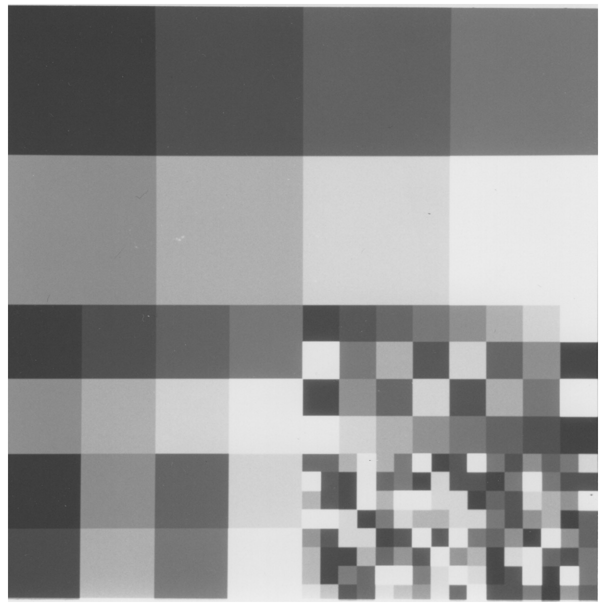
SIPI Lab – Powell Hall

Texture Analysis and Segmentation

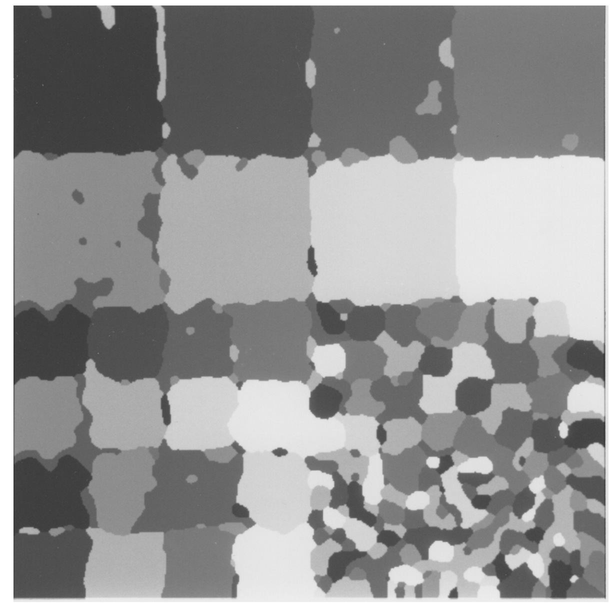
- Texture analysis and segmentation



original



labeled truth



result

John Hsiao, Allan Weber, S.-S. Jiang

Optics and Photonics in Computing

- Digital computer - bit (binary digit) - fundamental unit of information (0 or 1)
  - Logic elements (gates): AND, OR, NOT, etc.
  - Interconnections (communications) between gates, chips, boards, backplane, network
  - Memory

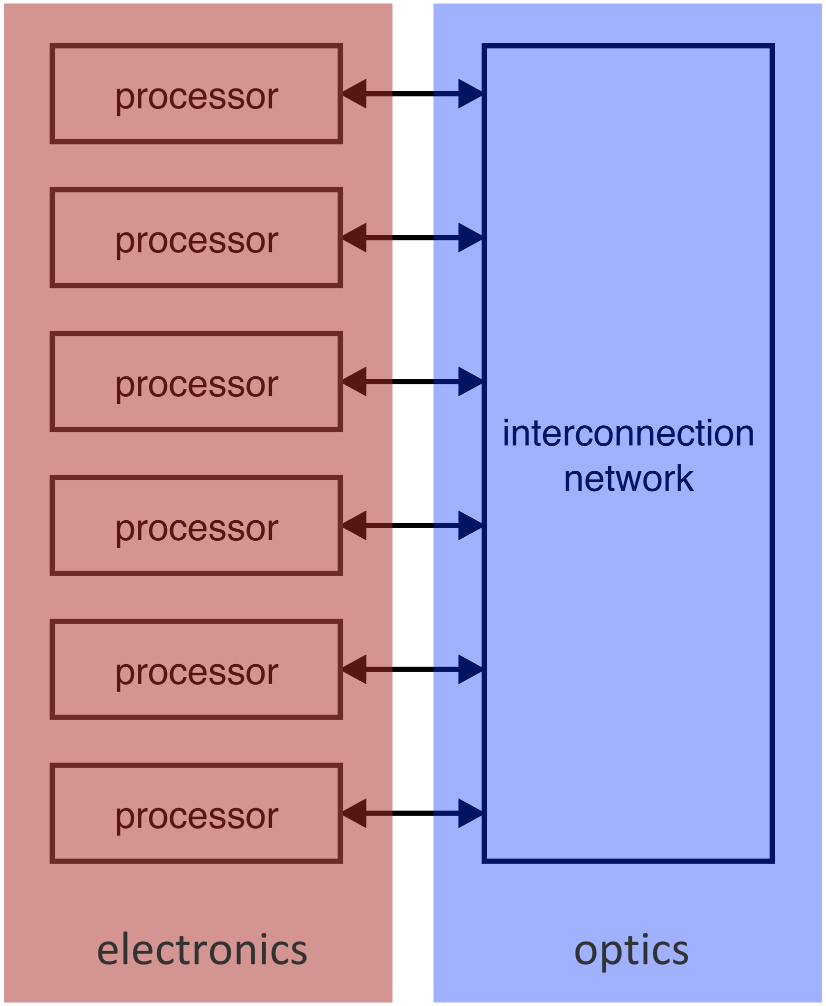
- Electronics (CMOS)
  - Great for logic
  - Bad for interconnections due to interference (cross talk)
    - electromagnetic signals interact at a distance
  - Slower than photonics

- Optics and Photonics
  - Great for interconnections -- light propagates through light in free-space
    - interference may be reduced
  - Bad for logic – light interacts with light through a medium or device
  - Faster than electronics (more than 1 trillion bits per second)
  - Use the third (volume) dimension?

Optical Interconnections for Electronic Processors

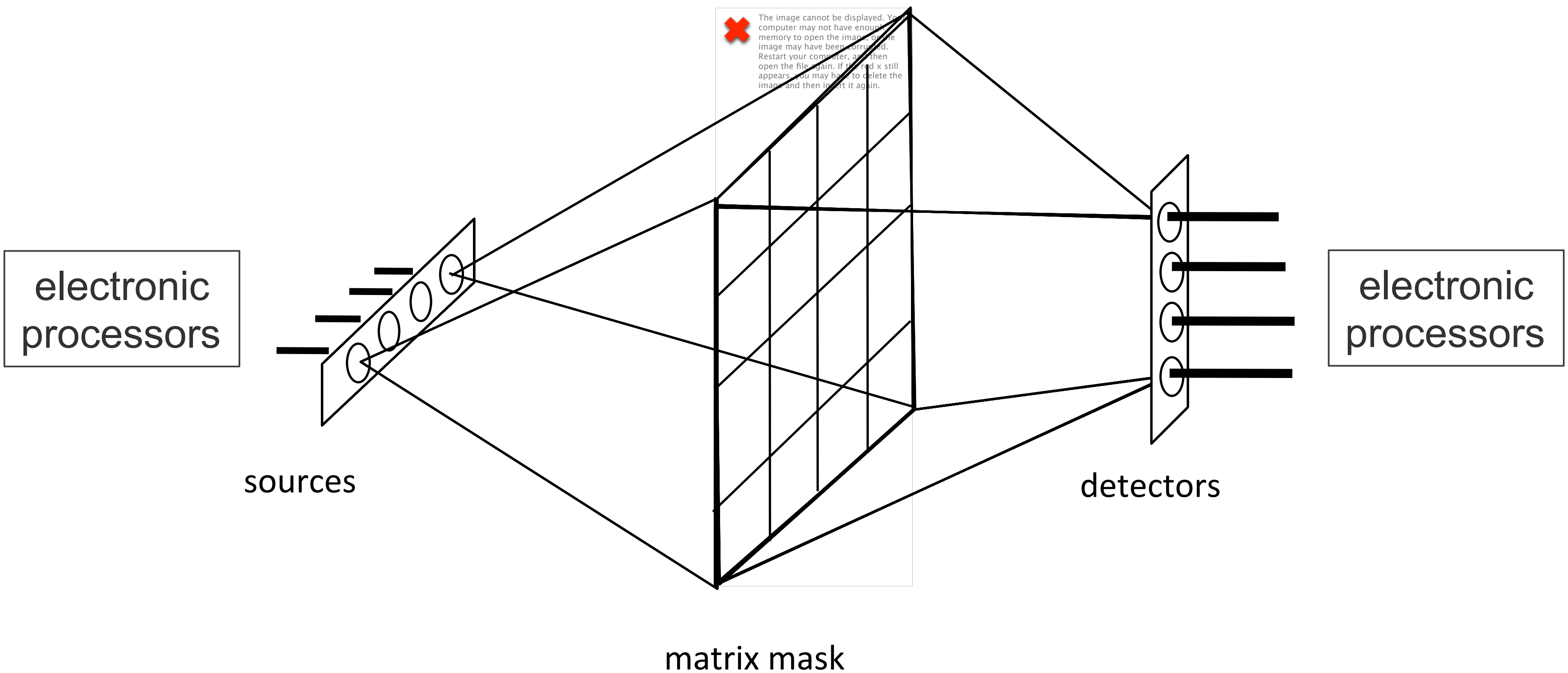
- Use complementary properties
- Optical interconnections
- Electronic digital processors

- Crossbar
- Shuffle interconnection network



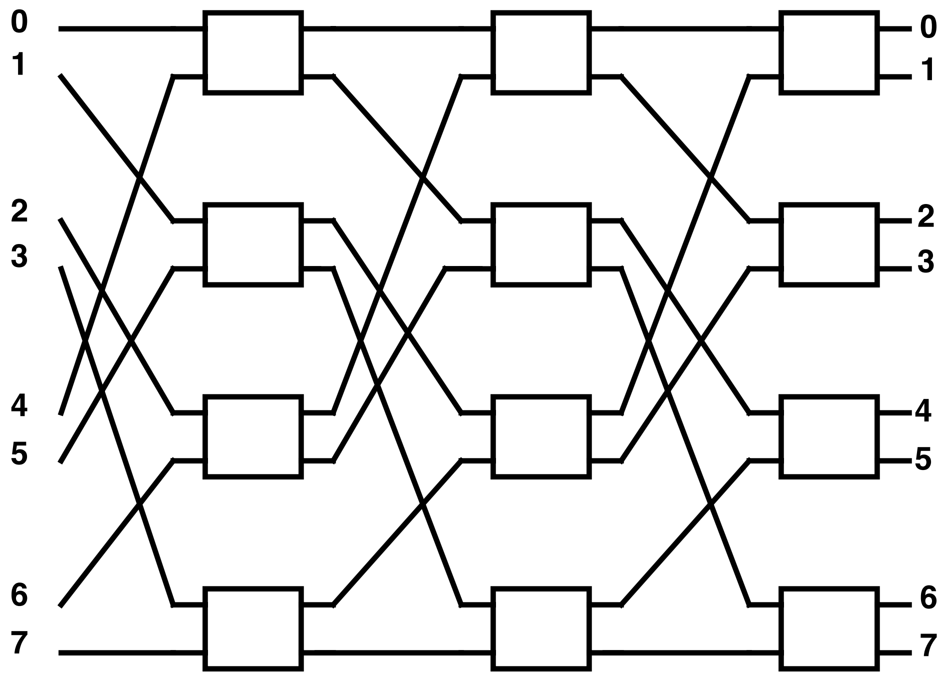
Crossbar (Matrix-Vector) Interconnection

Digital and analog valued linear vector-matrix operations



Planar (2D) Shuffle Network

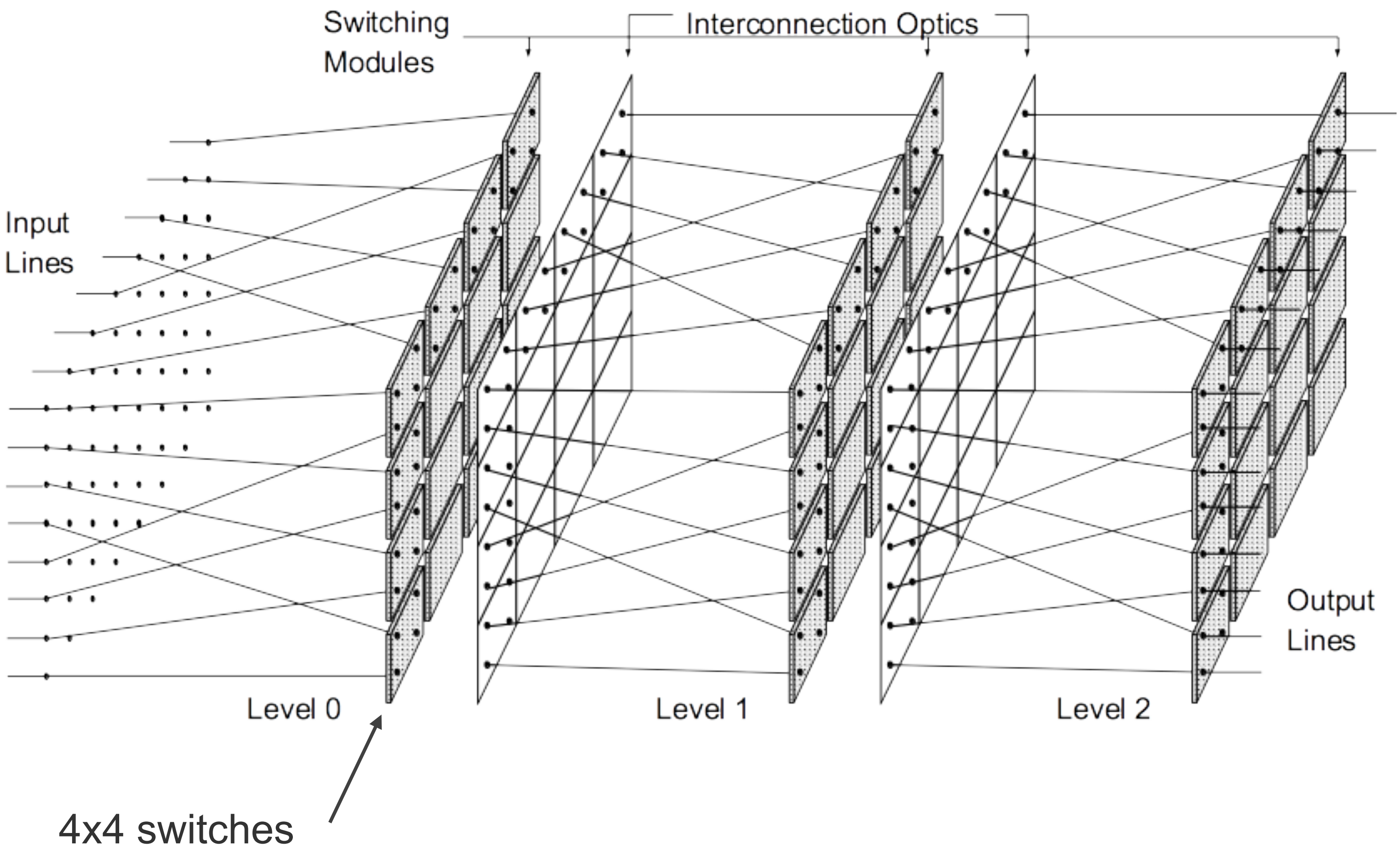
electronic processors



electronic processors

Shuffle interconnection network - 2x2 switches

3D Shuffle Interconnection Network

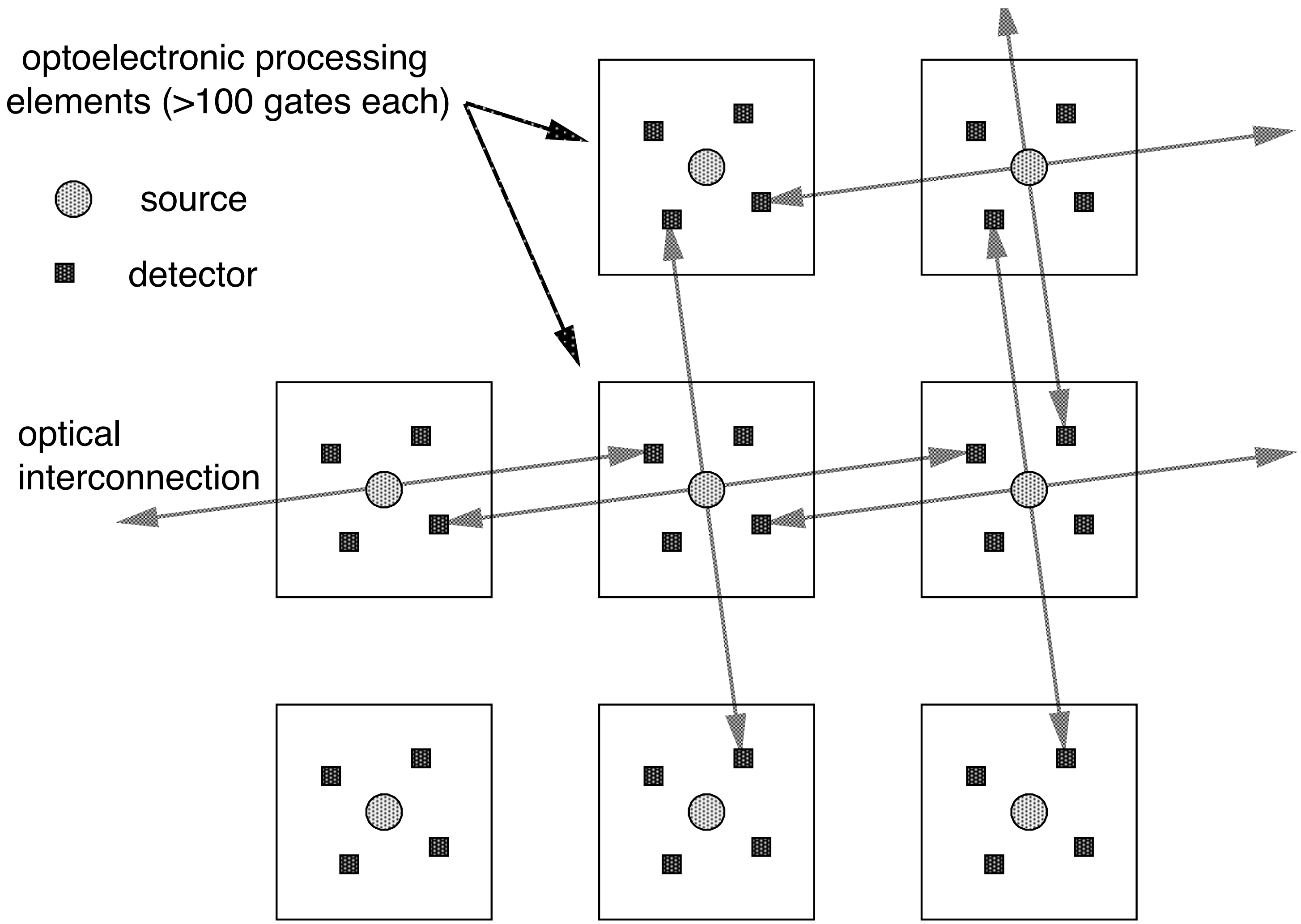


Lily Cheng

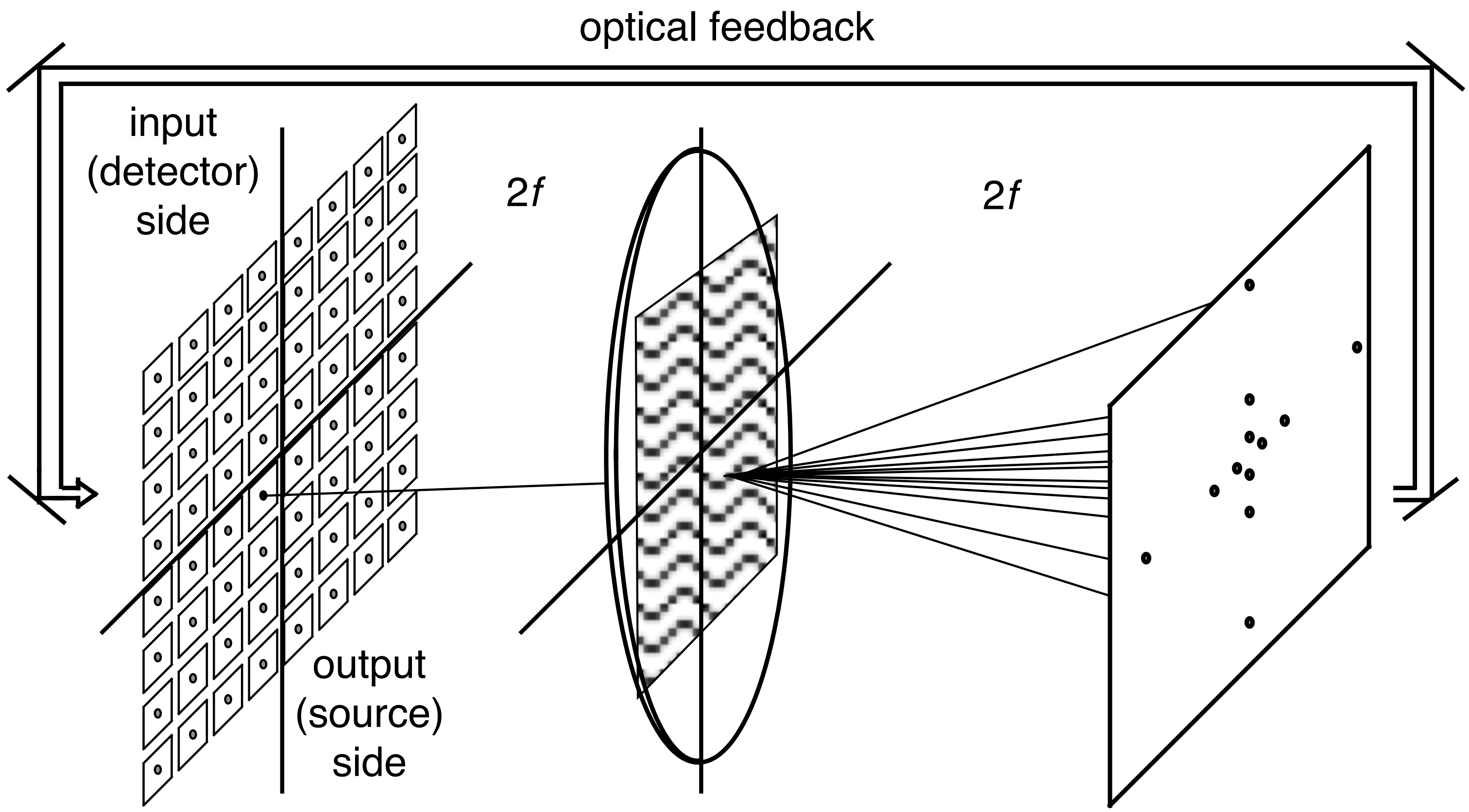
Optical Computing With Smart Pixel Devices

- Smart Pixel Optoelectronic Devices
  - integrated arrays of light detectors, sources, modulators
  - electronic signal processing circuitry (ideally) on a single substrate
- Optics
  - optical sources and detectors perform input/output and make long length interconnections to distant pixels on the chip
  - diffractive optics
  - binary or multilevel reflective or transmissive micro structures
  - made using photolithographic fabrication techniques
- Electronics
  - power efficient optical gates and signal amplification
  - electronic gates perform local logic operations at each pixel

Smart Pixel Cellular Array Processor



Smart-Pixel Cellular Hypercube



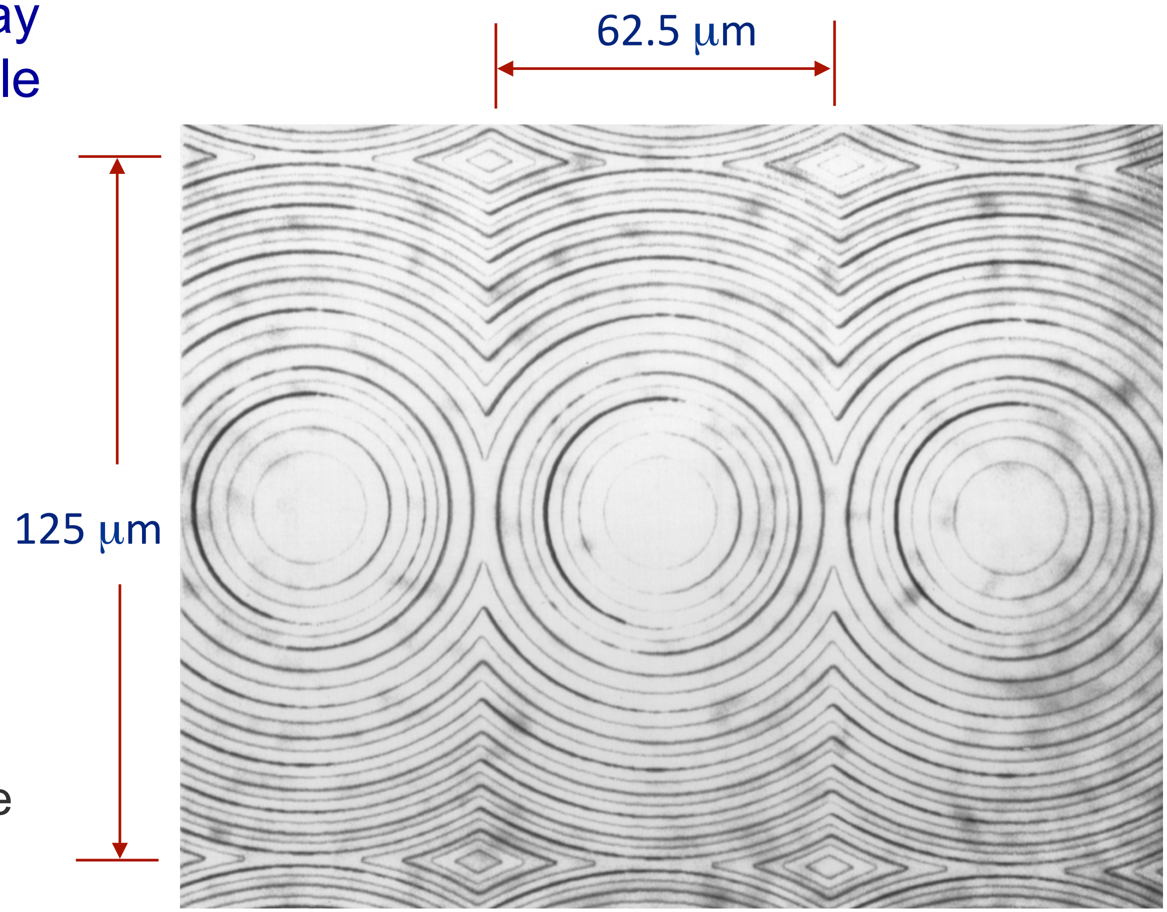
transmissive
processor
cellular array

transmissive
computer
generated
hologram $\underline{g}(x,y)$

F{$\underline{g}(x,y)$}

Diffractive Micro-Lens Array

- Diffractive microlens array provide compact, scalable imaging for SPAs
- Honeywell fabrication through CO-OP
- 10 x 20 array
- 62.5 x 125 μm aperture
- f/7 (1 mm focal length)
  - 8 phase level
  - 95% efficiency
- f/3 (300 μm focal length)
  - hybrid number of phase levels
  - 83 % efficiency

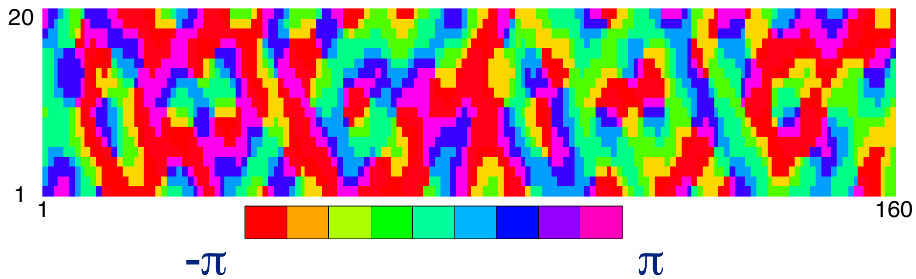


J.-M. Wang, C.-H. Wang

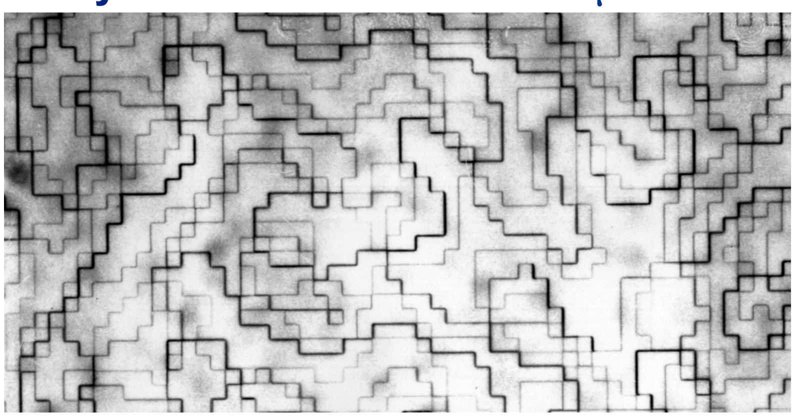
Diffractive Optical Elements (DOEs) for Spot Array Generation

- DOE performs spot array generation for parallel modulator readout
- Designed at USC, fabricated by Honeywell through DARPA CO-OP

DOE design - 20 x 160 phase elements

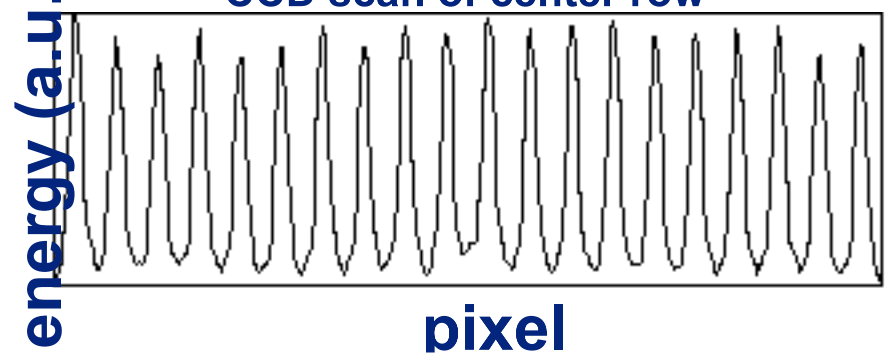


Honeywell fabricated with 5.1 μm features



optical power spectrum

CCD scan of center row



All-Optical Digital Computing

- Bottleneck: moving signals in and out of optical processors
- Electrical => optical => electrical conversion is slow and inefficient
- Computing entirely with optics

Digital Optical Computing

ALEXANDER A. SAWCHUK, SENIOR MEMBER, IEEE, AND TIMOTHY C. STRAND, MEMBER, IEEE

Invited Paper

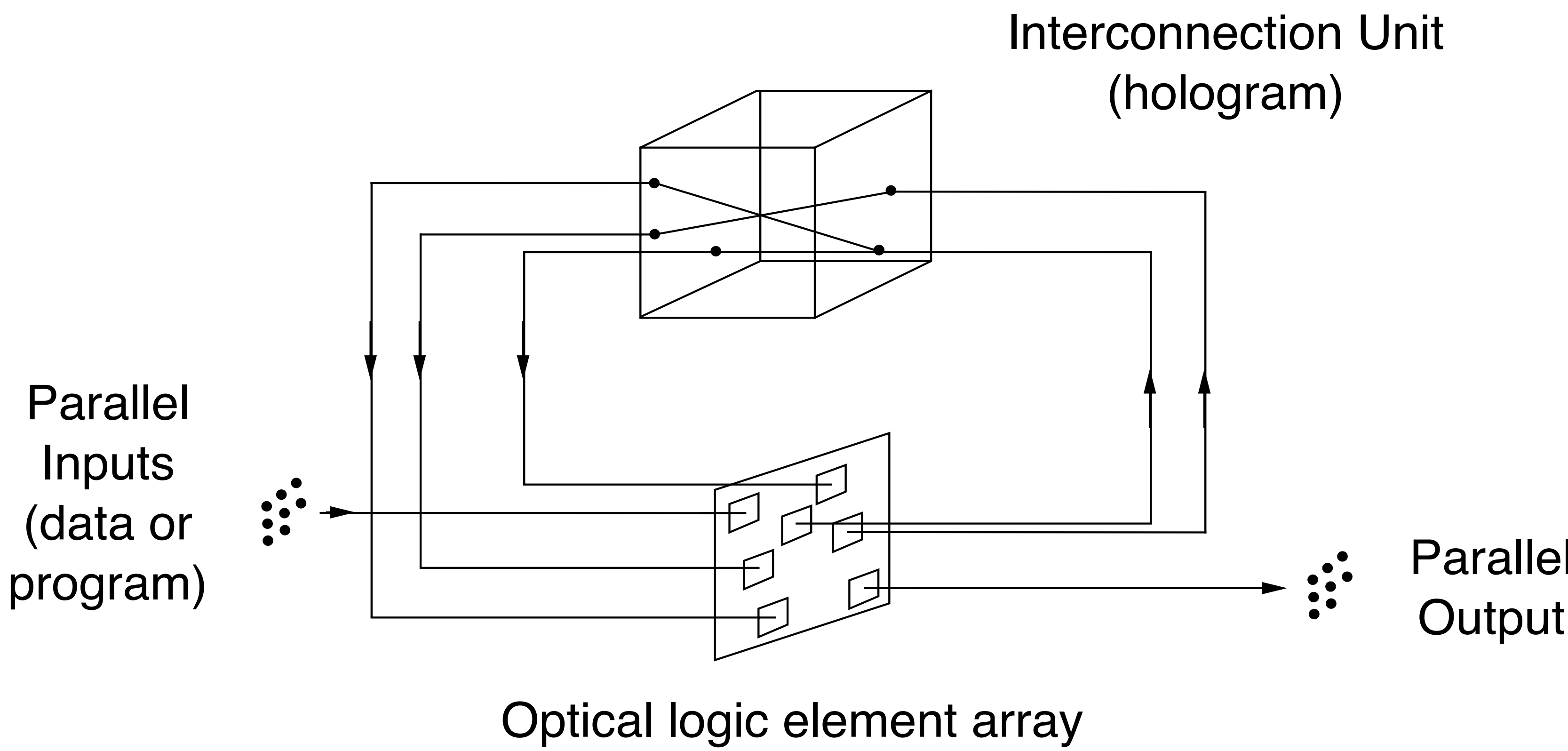
This paper concerns binary digital computing systems in which the information-carrying medium consists entirely or primarily of photons. The paper begins with a review of analog, discrete, and binary methods of representing information in a computer, followed by a survey of many techniques for implementing binary combinatorial and sequential logic functions with individual optical devices and arrays of devices. Next is a discussion of communication, interconnection, and input–output problems of digital electronic and optical computers at the gate, chip, and processor level. A particular architecture for implementing general sequential optical logic systems including digital optical processors is described. This architecture avoids some of the interconnection problems of electronic integrated circuits and VLSI systems, and offers the potential of non von Neumann parallel digital processors. Finally, the current limitations and future needs of optical logic devices and digital optical computing systems are outlined.

I. INTRODUCTION

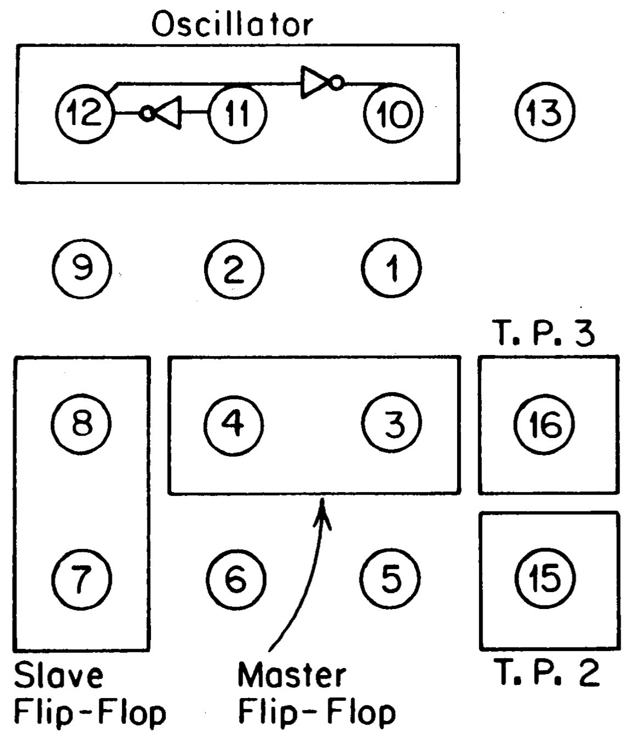
paper, these advantages have very promising implications for many traditional signal processing problems in which digital electronic hardware is inadequate. Some areas of digital computing that currently overburden existing technologies include image processing, radar signal processing, image analysis, machine vision, and artificial intelligence. This paper discusses these advantages in detail, along with disadvantages and limitations of various optical computing methods.

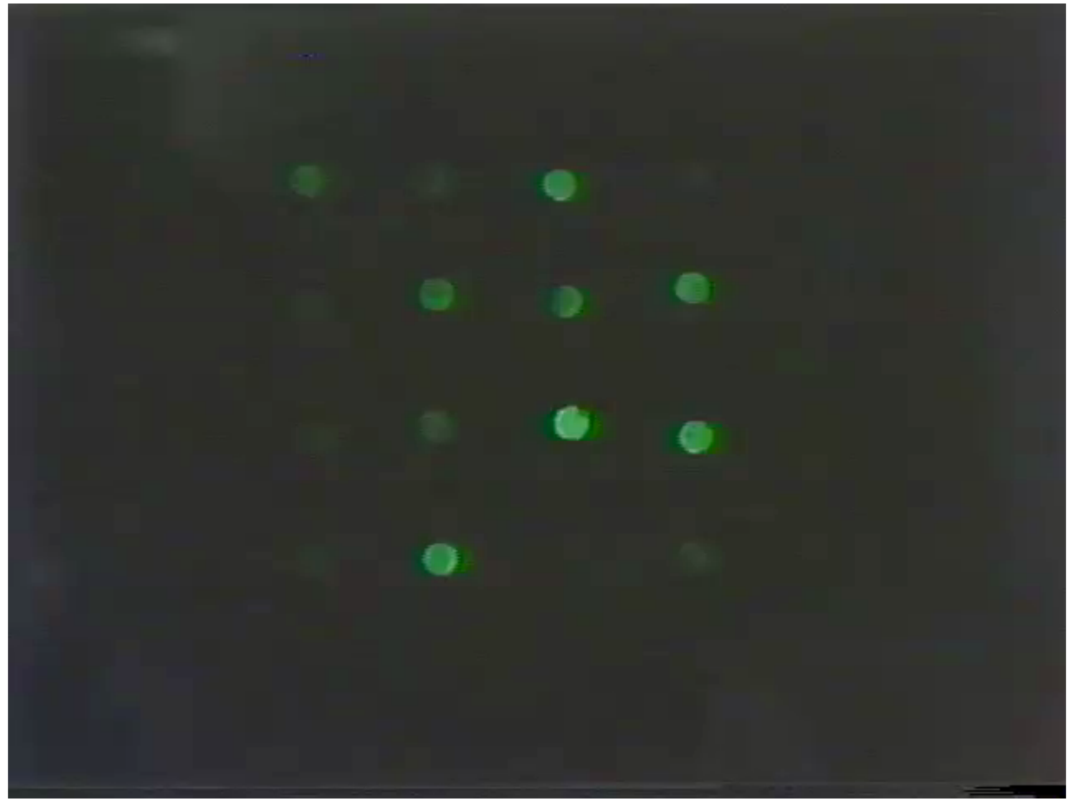
The eventual goal of the work described here is to perform binary digital computing with optical systems having photons as the primary information-carrying medium, avoiding electronic logic, and having as few photon–electron and electron–photon conversions as possible. We refer to such systems as digital optical processors (DOPs). Al-

Optical Parallel Computer



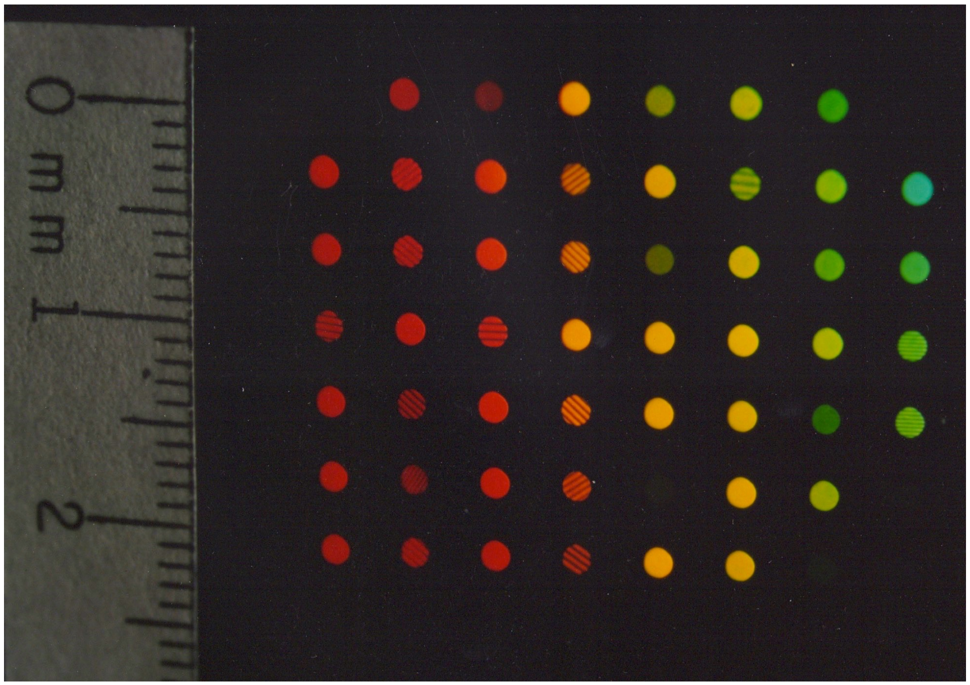
Sequential Optical Logic

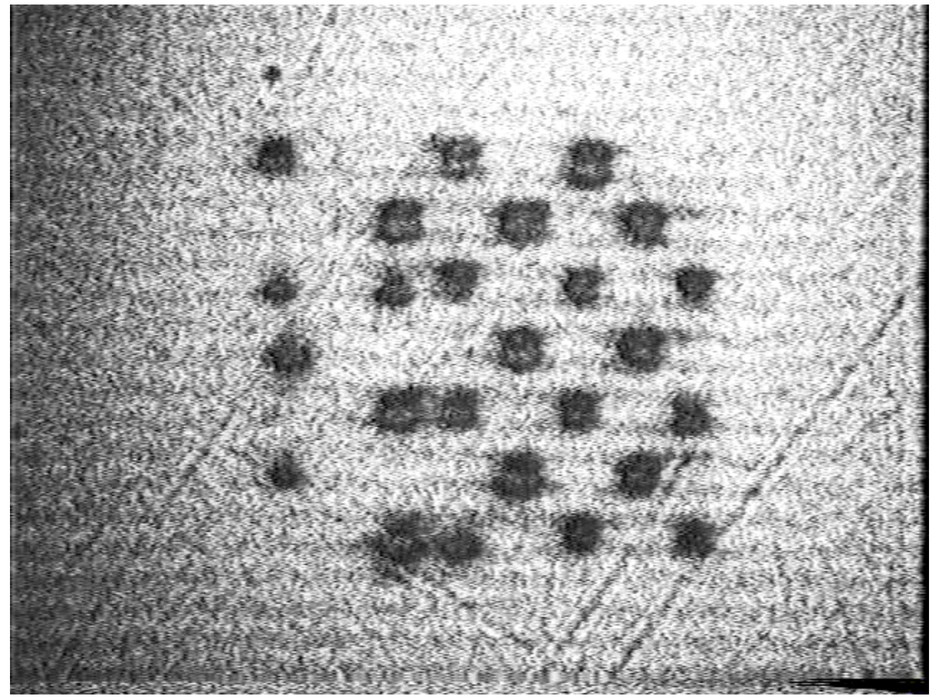




Keith Jenkins, Tim Strand, B. Soffer, R. Forchheimer

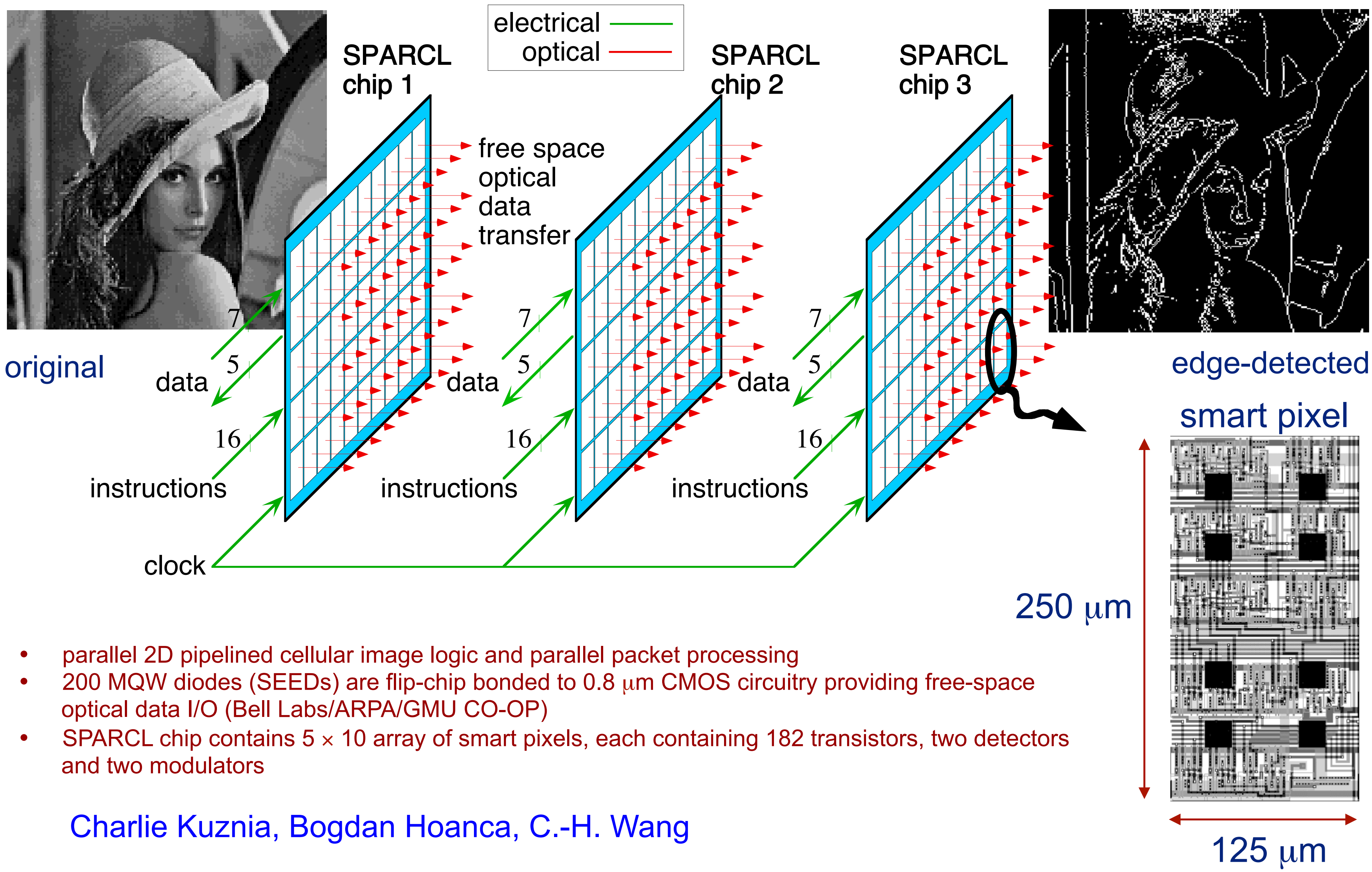
Digital Optical Cellular Image Processor (DOCIP)





Keith Jenkins, Tim Strand, Kung-Hsiuh Huang, Pierre Chavel, Allan Weber, J.-M. Wang, C.-H. Wang, I. Glaser

Hybrid CMOS-SEED
Smart Pixel ARray Cellular Logic Processor (SPARCL)

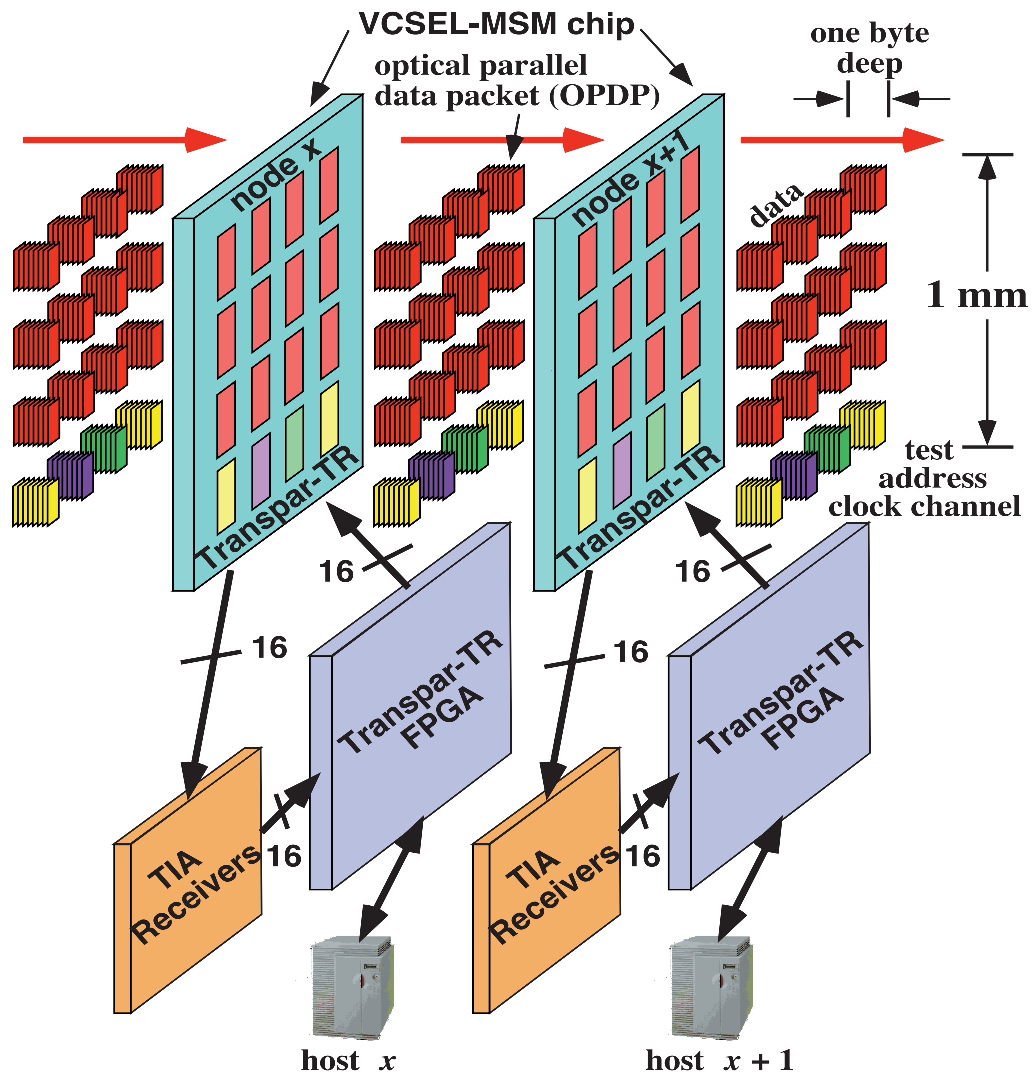


- parallel 2D pipelined cellular image logic and parallel packet processing
- 200 MQW diodes (SEEDs) are flip-chip bonded to 0.8 μm CMOS circuitry providing free-space optical data I/O (Bell Labs/ARPA/GMU CO-OP)
- SPARCL chip contains 5 × 10 array of smart pixels, each containing 182 transistors, two detectors and two modulators

Charlie Kuznia, Bogdan Hoanca, C.-H. Wang

Reconfigurable
TRANslucent Smart Pixel ARray (R-TANSPAR)

- Each network node has three chips (modules) that are integrated onto a PCB
- Field programmable logic array (FPGA) chip allows either CSMA/CD or Token-Ring protocol
  - CSMA/CD - simultaneous use of VCSELs and MSMs
  - Token-Ring - simultaneous use of VCSELs and MSMs ***not*** allowed
- Transimpedance gain of the receivers: 250 kΩ (from 20 μA photo current to 5 V logic)
- FPGA also implements 8-bit gray level image processing functions
- Altera Flex 10K (~200K gates)



National Projects and Centers

- University Research Initiative (URI) – Photonics - late 1980s – 1990s
- National Center for Integrated Photonic Technology (NCIPT) – 1990s
- Integrated Media Systems Center (IMSC)
- NSF-funded Engineering Research Center (ERC) 1996 - onward
- Immersive technology

The Move Toward

MEDIA IMMERSION

Dennis McLeod, Ulrich Neumann, Chrysostomos L. Nikias, and Alexander A. Sawchuk

Computer ©Superstock, Inc., book, cd, and film reel ©1996 PhotoDisc, Inc.

INTEGRATED Media Systems

The Media Immersion Environment (MIE), a vehicle for the system integration of multimedia engineering and other scientific developments, has a robust system infrastructure for the implementation and demonstration of multiple, diverse system applications in a simulated operational environment. An evolutionary platform that will change dynamically over time, the MIE serves as a national test bed for the integration, evaluation, and demonstration of advanced multimedia technologies. Inherently multidisciplinary, the MIE encompasses all media systems integration efforts to create powerful, advanced media systems.

Today, the integrated media system is a computer-based facility that supports the creation, sharing, distribution, and effective communication of multimodal information across the boundaries of time and space. It is rising to the forefront as the information technology milestone for the next decade, expanding the way we communicate, work, and conduct business.

The MIE provides a framework for the creation of various integrated media systems, offering an overarching, unifying theme for "fitting together" the different information technologies. In an integrated media system, advanced media technologies are used to combine, deliver, and transform information by way of images, video, audio, animation, graphics, and text in real time.

In the near-term, it is expected that the following functionality will be supported with the MIE:

- Real-time video and spatial audio with head tracking
- Storage of and access to immersipresence sessions
- Connectivity to Internet database resources
- High-speed networks and interfaces with customized protocols

The mid-term MIE will go several steps further, providing:

JANUARY 1999 IEEE SIGNAL PROCESSING MAGAZINE 33

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Cooperative Immersipresence: Concept

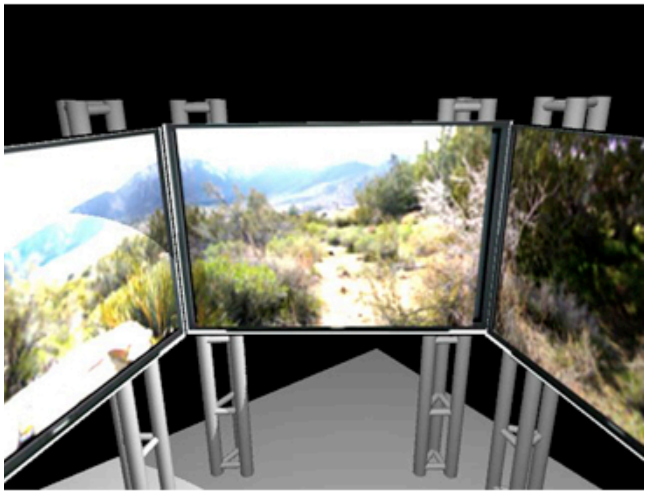
Meeting Places

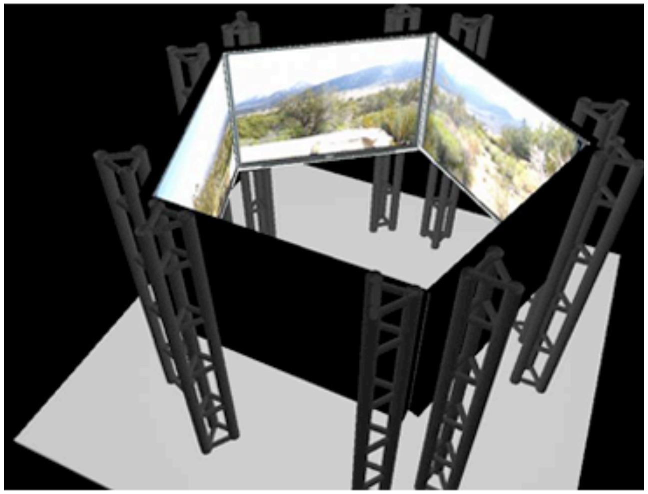
- Immersivision, immersive audio, haptic interfaces
- High-speed heterogeneous networks, digital video, compression, wireless
- Multimedia database storage, access, sharing, customization (the cloud)

Immersive Teleconferencing

Roger Zimmermann, Chris Kyriakakis

Panochamber

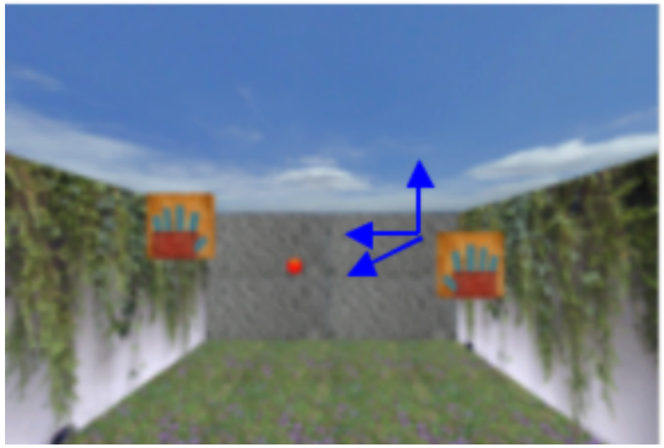




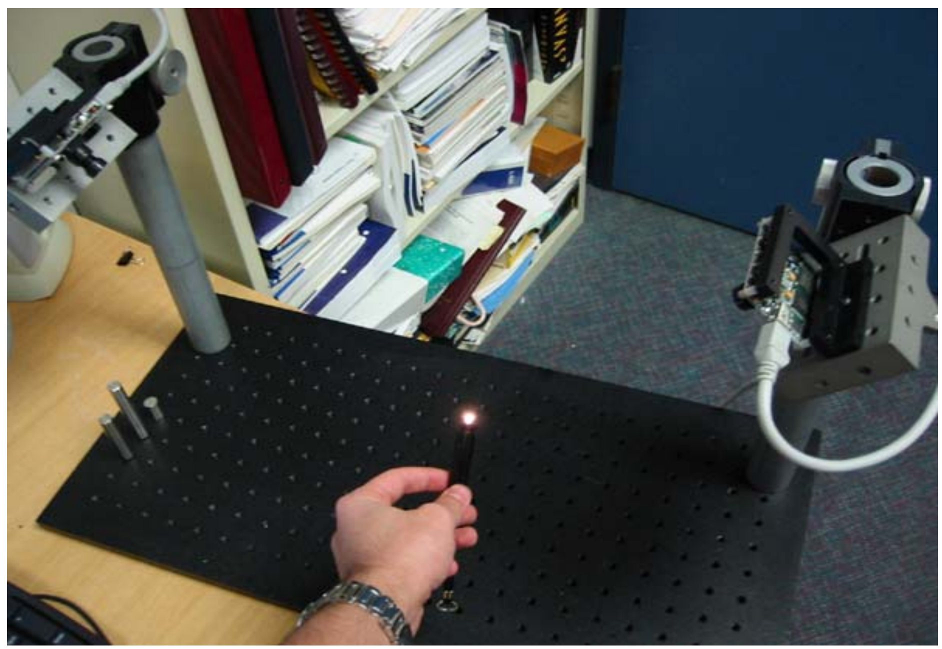
Now: augmented reality (AR), virtual reality (VR)
But: glasses or head gear needed!

Skip Rizzo, Allan Weber, Luke Yeh, Ann Page

3D Displays and Interaction Devices



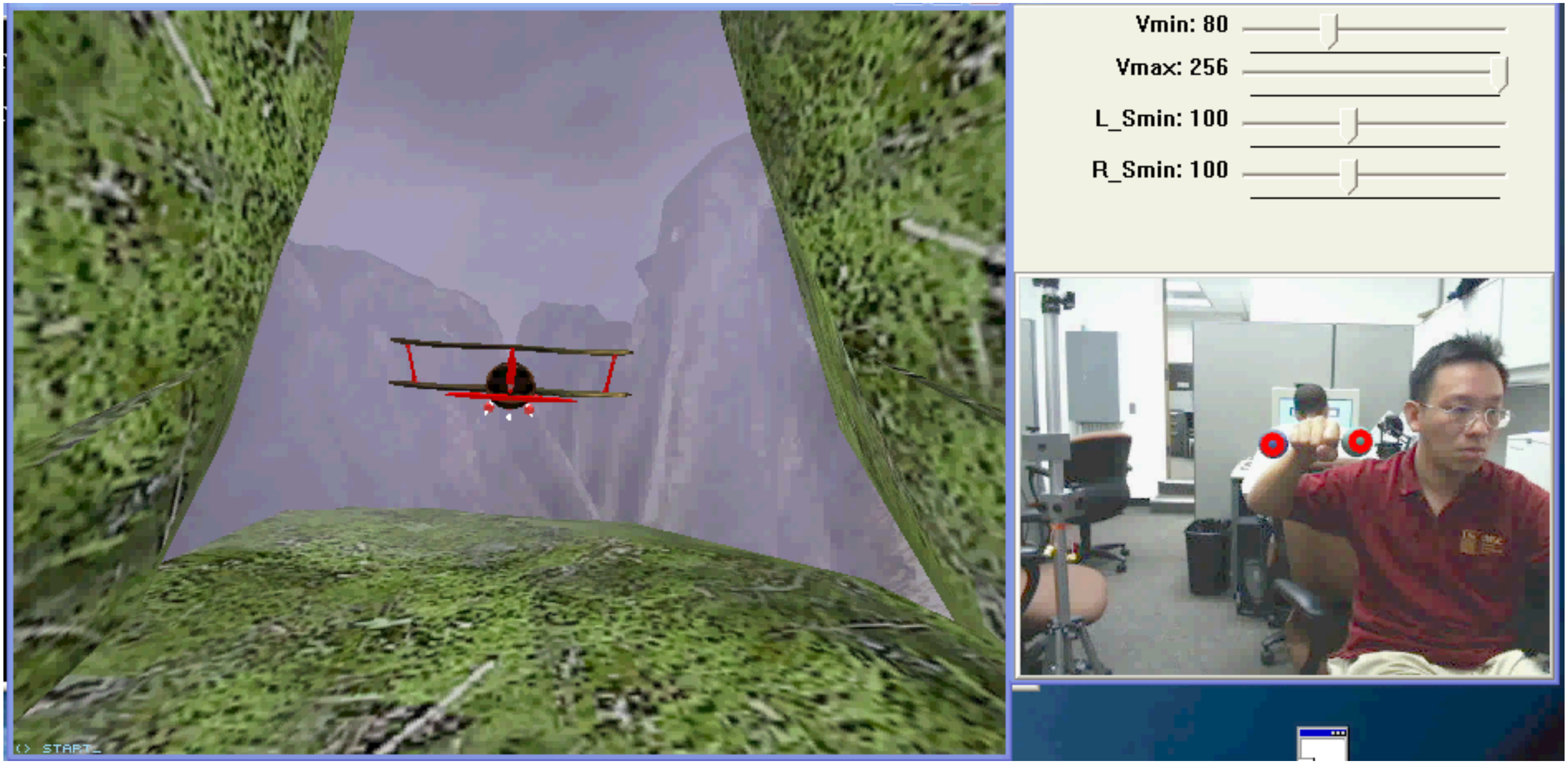
- 3D displays
  - rehabilitation
  - stroke
  - injury



- 3D interaction
  - 3D mouse

Zahir Alpaslan

3D Interaction



- Blue, green balls on a stick – webcam tracking
- Luke Yeh

Service

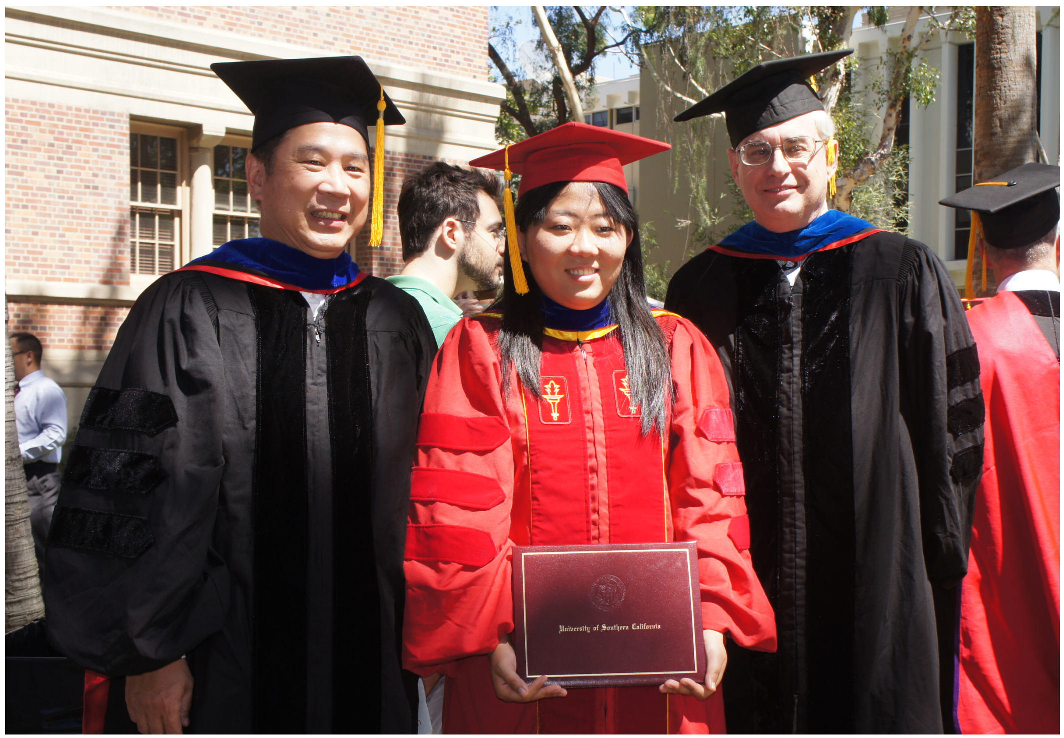
- USC
- Department
  - Chair EES 2005-2012
- Viterbi School of Engineering
- University

- External
- Professional societies: OSA, IEEE, SPIE, etc.
- Meetings, program committees
- Panels

- Board Chair OSA Foundation

Teaching, Education, Students

- Taught many different courses
- Distance Education Network (DEN)
- Students: BS, MS, PhD
- 40 PhD graduates



Thanks

- Faculty and colleagues
  - Keith Jenkins
  - Tim Strand
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  - Krishna Nayak
  - Panos Georgiou
  - Armand Tanguay, Jr
  - C.L. Max Nikias
  - Jerry Mendel
  - Richard Leahy
  - Antonio Ortega
  - Chris Kyriakakis
  - Shri Narayanan
  - Skip Rizzo
  - Roger Zimmermann
  - Elaine Chew
  - Dan Dapkus
  - Alan Willner
  - Ron Smith
- Staff
  - Gloria Halfacre
  - Allan Weber
  - Seth Scafani
  - Mayumi Thrasher
  - Alma Hernandez
  - Gerrie Ramos
  - Diane Demetras
  - Ted Low
  - Tim Boston
  - Marilee Reynolds
  - Talyia White
  - Cathy Huang
  - many others…
  - Ming Hsieh Institute
- Family
  - Mariette Sawchuk
  - Mark Sawchuk
  - Steve Sawchuk

Hughes Aircraft Electrical Engineering Center – SIPI Home 1991

Thank you!