Sensor Arrays, Artificial Senses, Awareness, Intelligence

ELECTRONIC- NOSE, TONGUE, EYE, PANCREAS, EAR, TOUCH

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Artificial Sensing: Summary

- What is artificial sensing?
  - An instrument/prosthetic to obtain awareness of the real world!
  - Our safe and harmonious link with others and with mother nature!
- Why do we need sensing?
  - Provide total situational awareness, interact effectively, safely.
  - Protect our planet and its inhabitants.
- What are the Global Implications? OPPORTUNITIES!
  - Sensors crosscut international industrial markets & social uses.
  - We need to improve safety, security, and the natural harmony of our cities.
  - Trade, commerce, and international cooperation.

Robots are fascinating because they mimic humans + tools!

San Francisco California, USA Museum, 2003. Joseph Stetter & Robbie the robot

Sensing with sensor arrays?

Sensors: Chemical, Physical

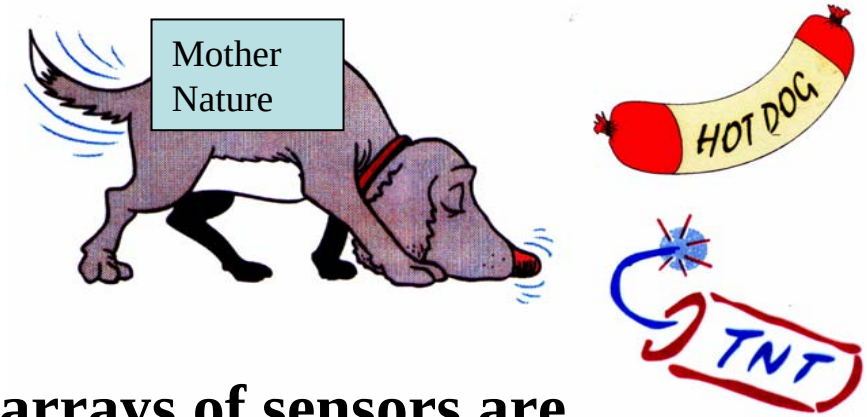
- History
  - Sensors
  - Arrays [e.g. e-Nose]
- Examples
  - Europe
  - Asia
  - North America
- Future
  - Promote international business cooperation
  - International Scientific development.

Electronic Nose/CPS100, Stetter, et al. 1985

Exemplary “electronic”& “electrochemical” sensors: Measurements of toxics, oxygen, acidity, air quality.

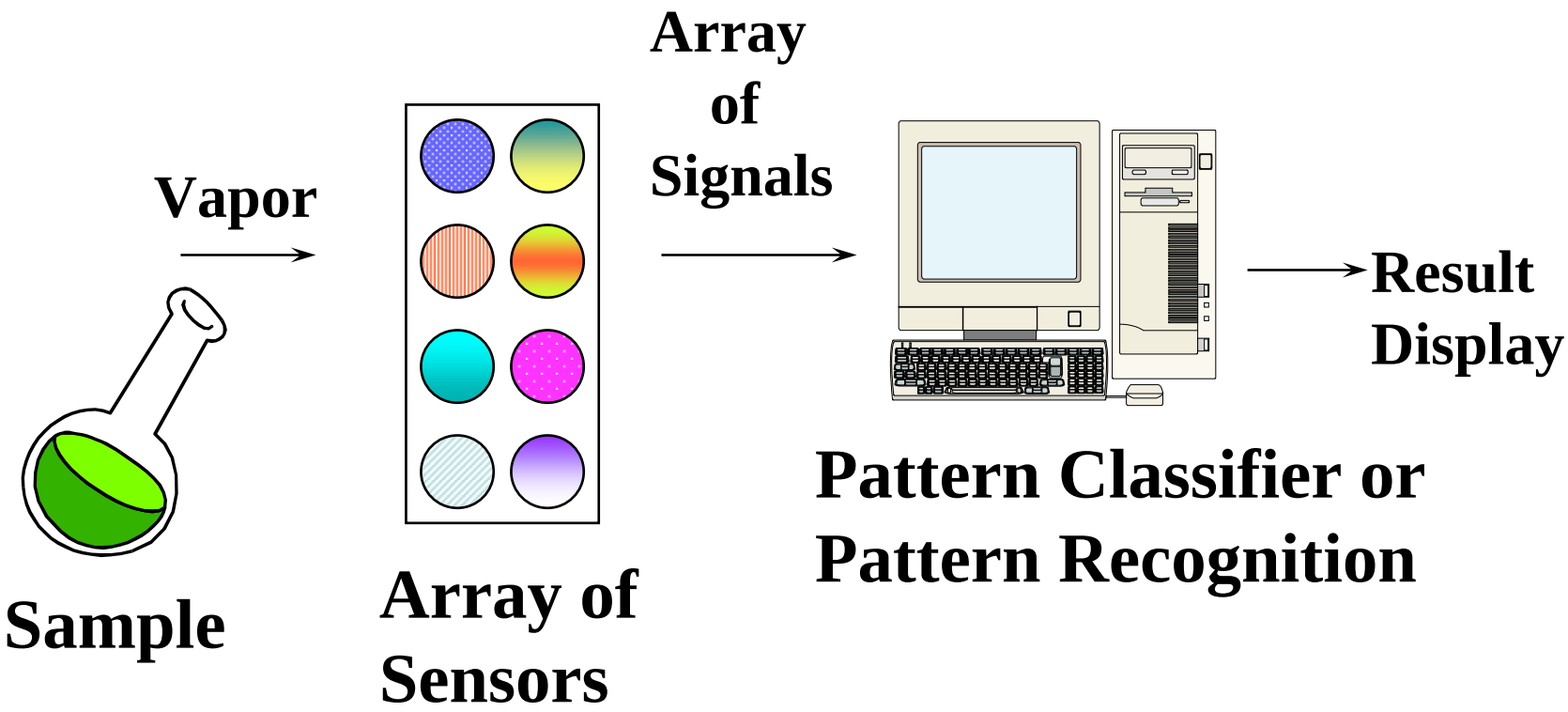
SAMPLER + SENSOR/SIGNALS + BRAIN + DISPLAY

Electronic Instrument



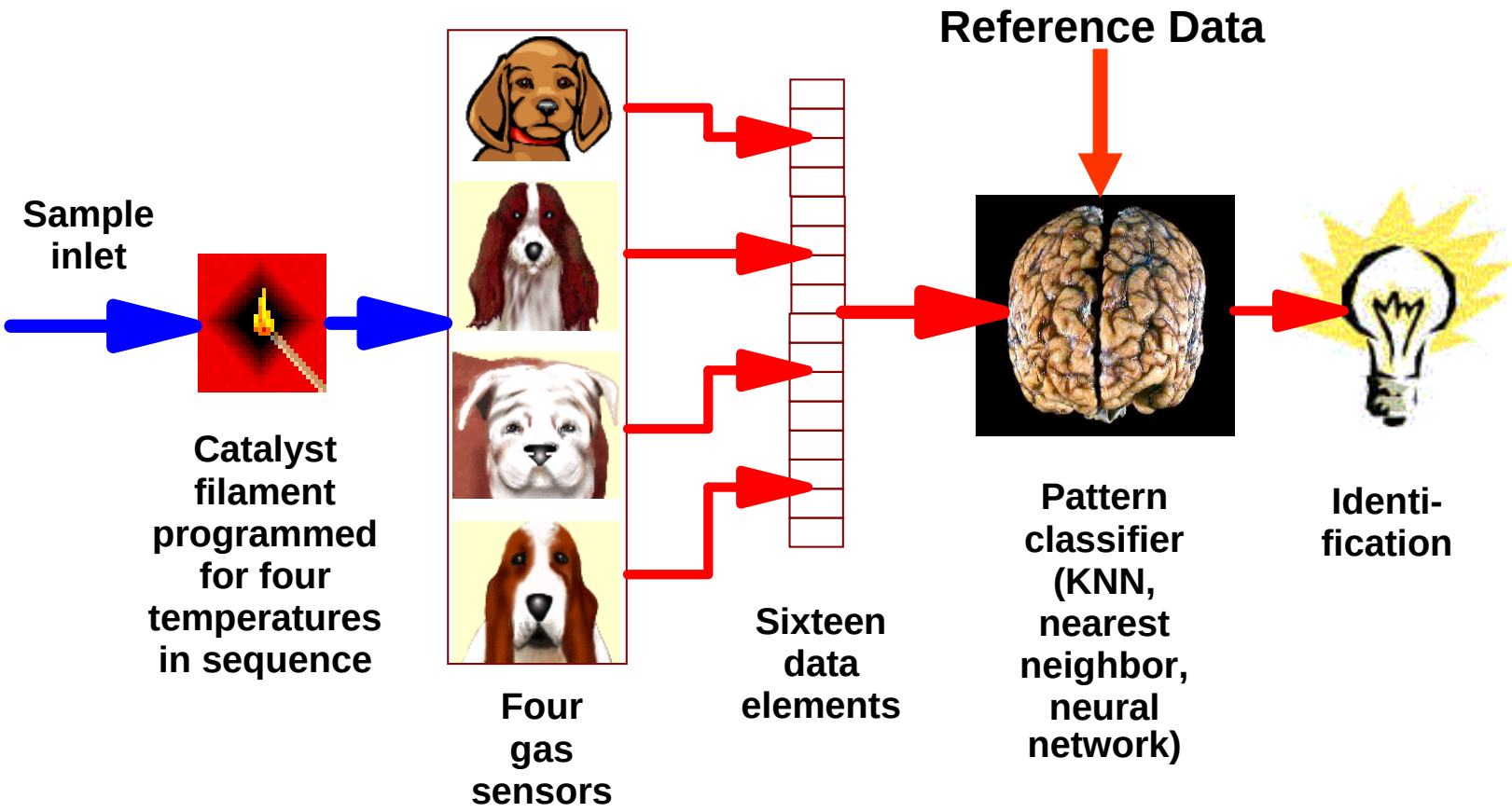
Sensor Systems made with arrays of sensors are more powerful than sensors alone!

The Electronic Nose is one good example of Chemical Sensor Arrays



And of international cooperation in sensor technology development!

Operation of the "ILLI-Nose"



Four sensors x four temperatures = 16 "virtual sensors"

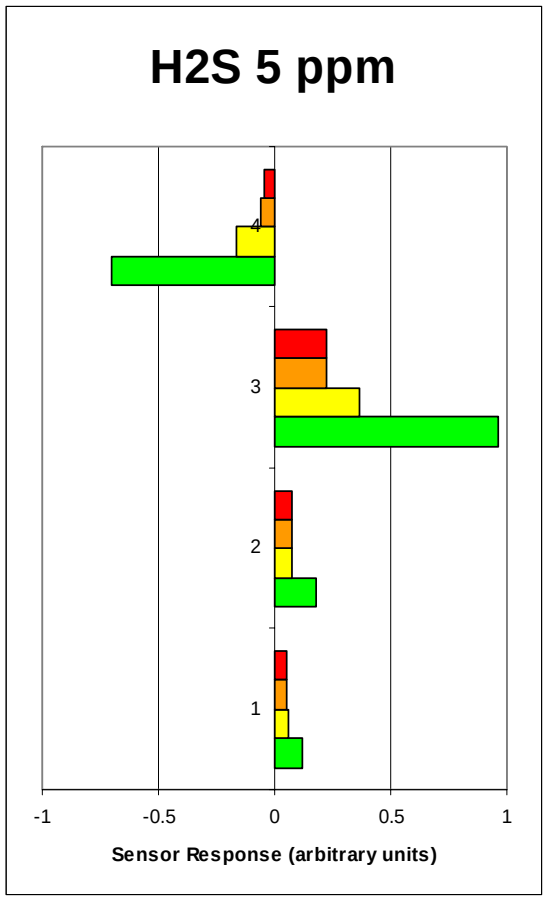
Portable Version E-Nose, ~ 1983 [CPS-100; DEVELOPED AT ANL]

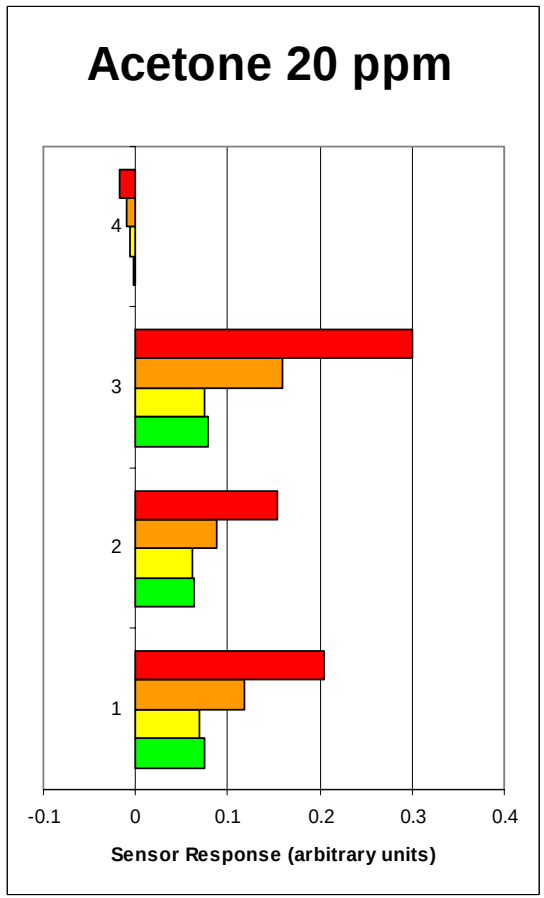
- Portable w/software
- Four sensors operated in four modes (ie, 16 channels of information)
- Library of >30 solvents Odor Vapors or gases
- Battery-operated for 6 hours

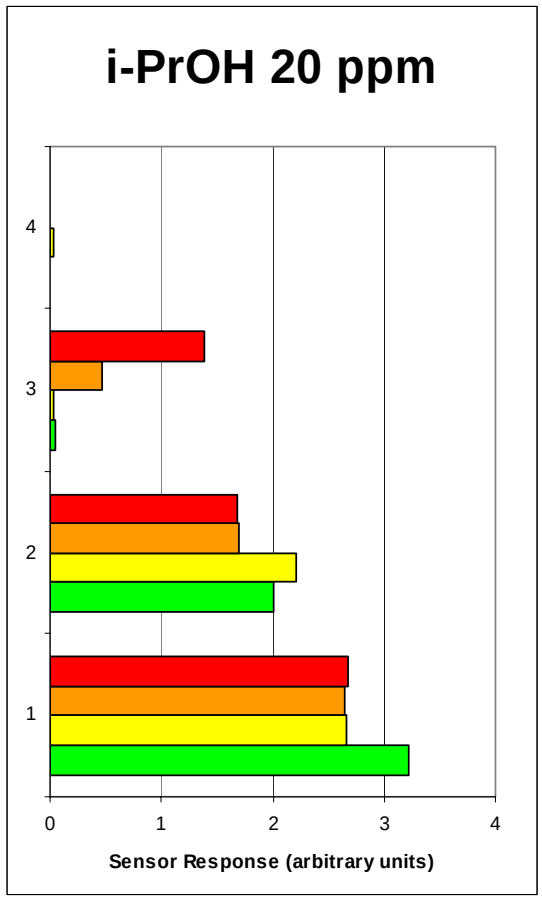
Ruggedized Version for Commercial Sale →

Licensed to Transducer Research, Inc., 1986
www.transducertech.com

Solvent Sensor Responses After Feature Extraction







Patterns of compounds by CPS-100 e-Nose!

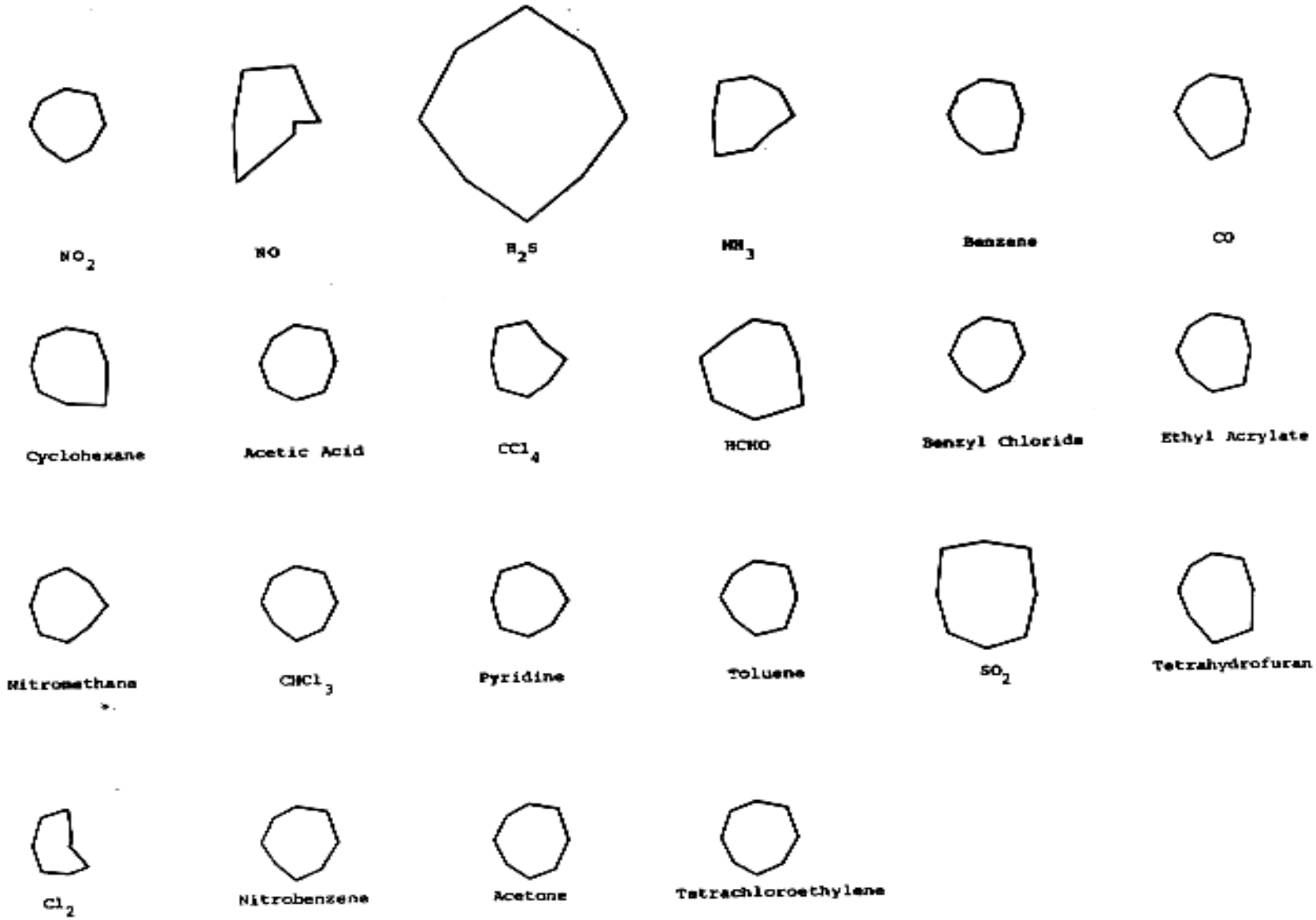
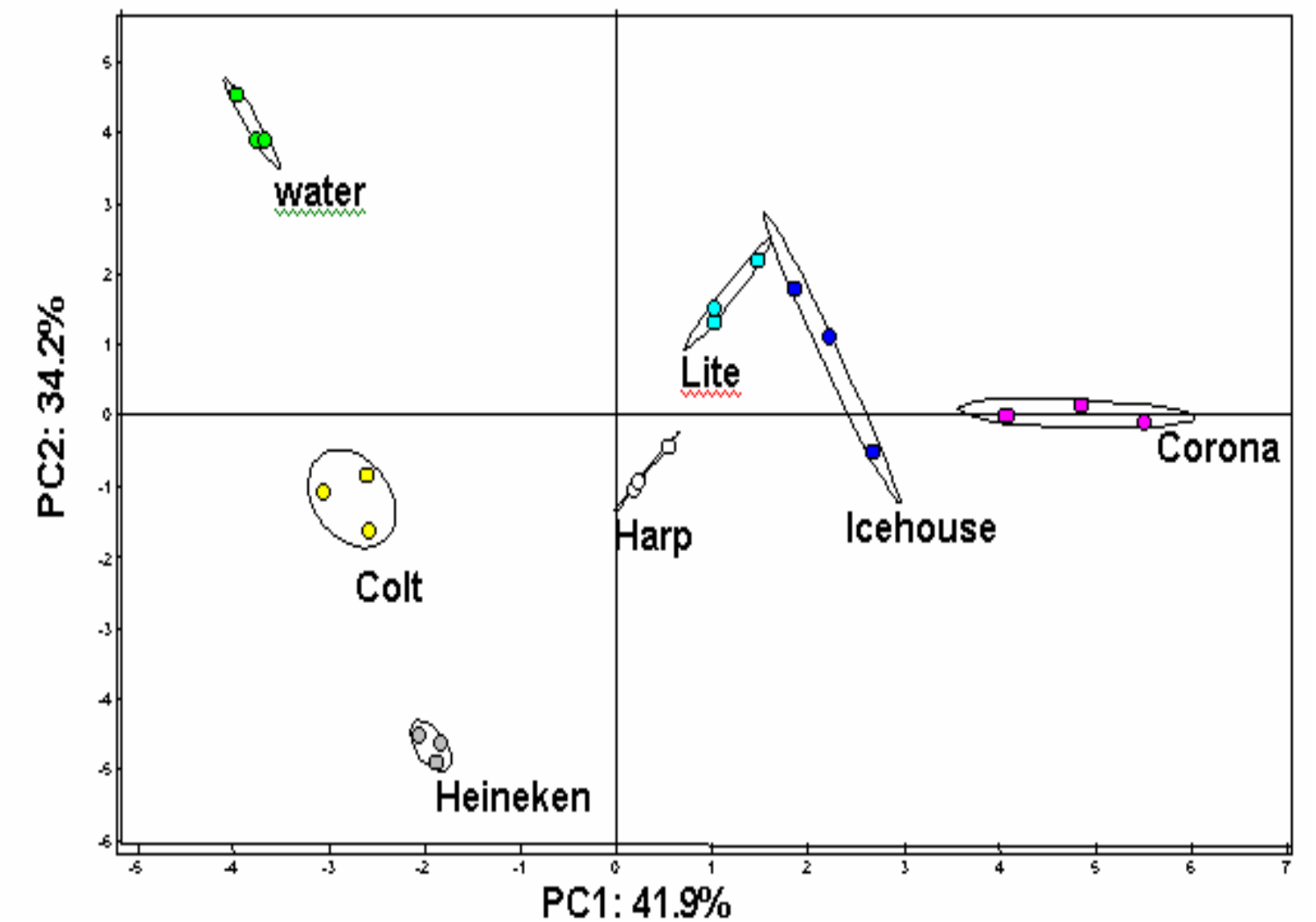


Figure 3. Circular profiles of the data set using 8 rather than 16 channels.

Stetter, J.R., P.C. Jurs, and S.L.Rose, "Detection of Hazardous Gases and Vapors: Pattern Recognition Analysis of Data from an Electrochemical Sensor Arrays," Anal. Chem. 58, 860-866 (1986).

E-Nose Allows Discrimination of Beers!



Principal component analysis of beer vectors using a 20-sensor array e-Nose with 3 orthogonal sensor classes.

Stetter, DeCastro, et al. 1999

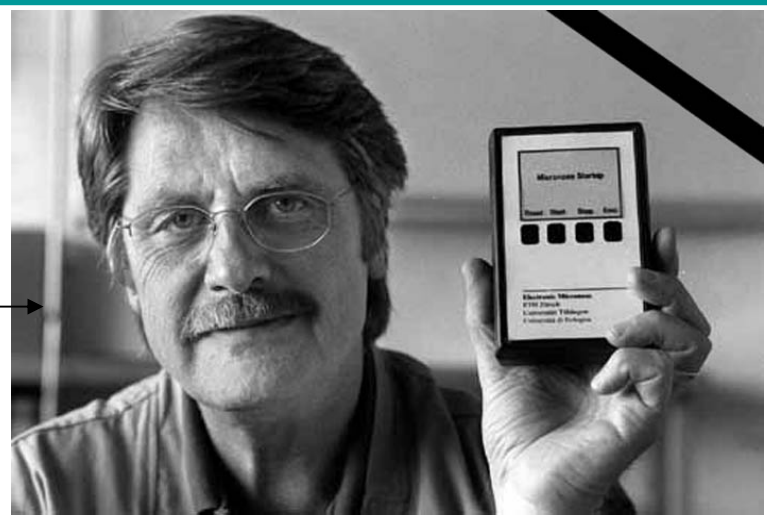
Electronic Nose!

- An electronic nose is an ***instrument***, which comprises *a* ***sampling system***, an ***array of chemical sensors/signals,*** and an appropriate ***pattern-classification system*** with readout, typically applied to the qualitative and/or quantitative analysis of gases, vapors, ***odors***, or mixtures.

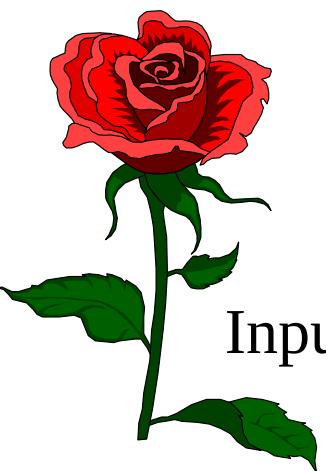
In principal any sensory data can be likewise used!

- Liquid sensor array = Electronic tongue
- Biosensors/Immunosensor array = electronic pancreas, …
- Light sensor array = electronic eyes
- Acoustic/vibration sensor array = electronic ear
- Heat sensors, Touch sensors, force sensors, charge sensors, GC, MS, ….

@1998 micro e-Nose developed by Prof. W. Göpel, Prof. H. Baltes, et al.
W. Göpel [31 Oct.1943 - 14 June, 1999]



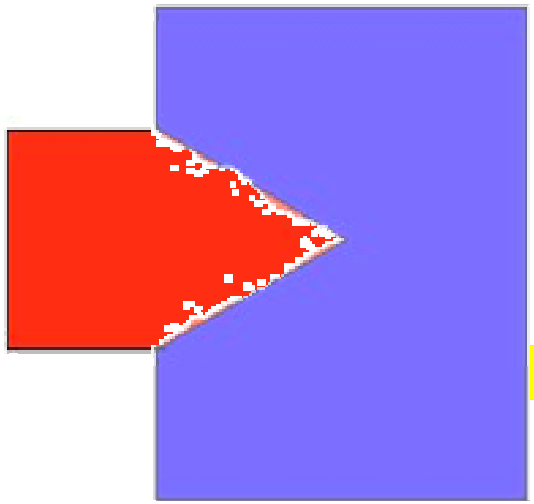
How Does a Biological Nose Work?



Input

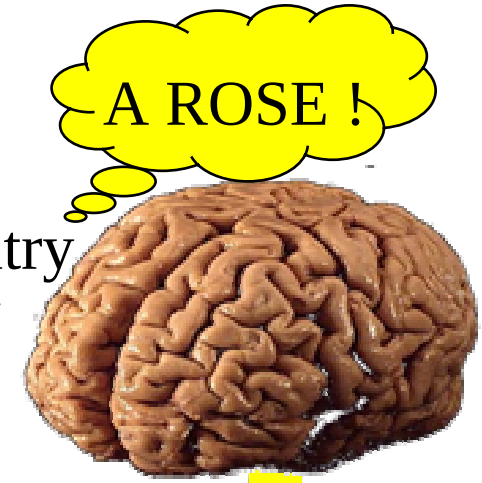
Mucus (filter)

Receptor Protein (sensor)



Nerve

Circuitry & NN



The Electronic Nose evolved from sensor & olfactory research in Asia, America, and Europe!

- Interdisciplinary:
  - pattern recognition; chemometrics.
  - chemical sensors;
    - MOX, Electrochemical, SAW, QCM, thermal, optical, polymer, …
  - micro-computers;
  - human olfaction.

- Pattern recognition -1970s for structure-activity relationships
- Chemical Sensors: Beckman 1935, Seiyama 1956, Heiland 1960.
- Persaud/Dodd, 1982,mimic of olfactory system with MOX.
- Stetter, et.al, 1980-4. CPS100 **Portable Instrument** e-Nose with pattern recognition.
- Ikegami, Kaneyasu, 1985 array for odor quality.

CPS/100 portable sensor array e-Nose. **J.R. Stetter**, et al.,"Portable Device for Detecting and Identifying Hazardous Vapors," Journal: Hazard. Mater. Spills Conf. Proc., Prev., Behav., Control Cleanup Spills Waste Sites, Editor: Ludwigson, John (Ed), Date: 1984 Pages: 183-90. paper 116 Government Institutes Inc., (pub.), Rockville, MD, 20850, Apr., (1984).

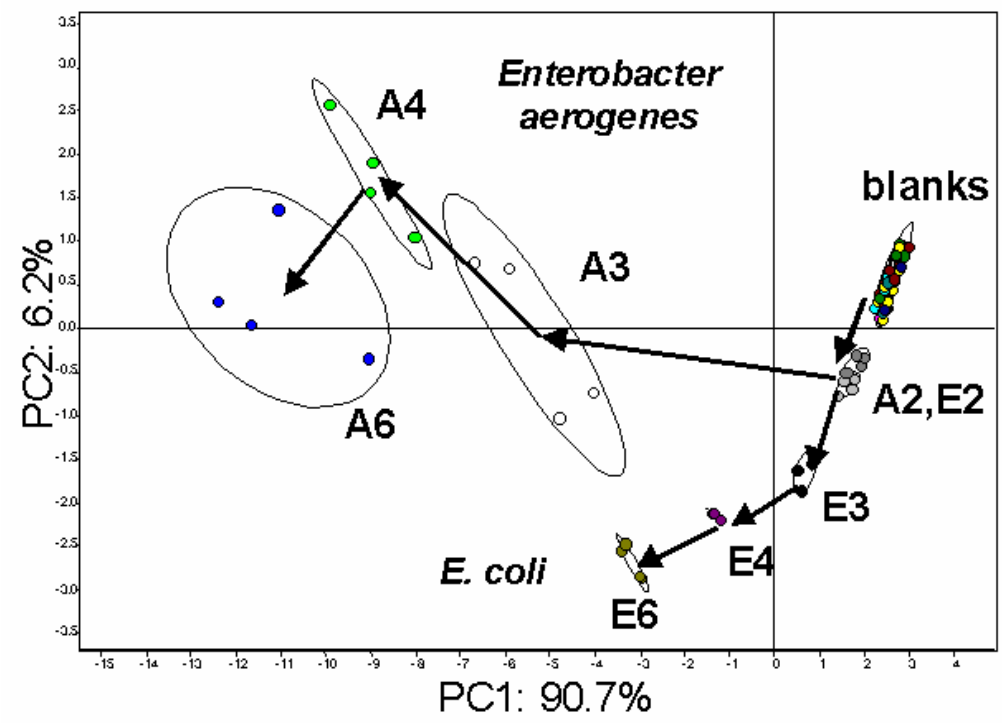
CPS/100 portable sensor array e-Nose.
Camera bag size, 12 lbs [6 kG]
Indentified and quantified 30 chemicals
Internal sampling pump
4 sensors with one filament & 4 modes
KNN pattern recognition
Real-time display
Push button ID function
Battery operated.(1984).

E-Nose can detect/identify Bacteria!
BACTERIAL CHARACTERISTICS differ!

Parameter	E. coli	Salmonella cholereasuis	Enterobacter aerogenes	Klebsiella pneumoniae
Mixed acid (methyl red)	+	+	-	-
Butanediol (acetoin)	-	-	+	+
Indole	+	-	-	-
H_2S	-	+	-	-
Ornithine Decarboxylase	some	+	+	-
Urease	-	-	-	+

Ref: Discrimination of Enteros from E. coli [McEntegrat, PhD thesis, IIT 2002]
[McEntegart. Stetter, et al., *Sensors and Actuators B70*, 170-176 (2000)]

Exemplary identification of bacteria using an Electronic Nose: Data displayed in principal components plot.



***Enterbacter aerogenes* and *Escherichia coli* diverge and can be identified as distinct after 1 hr. of growth (3 - 5 . 10^8 cells/mL) [McEntegart et al., *Sensors and Actuators B70*, 170-176 (2000)]**

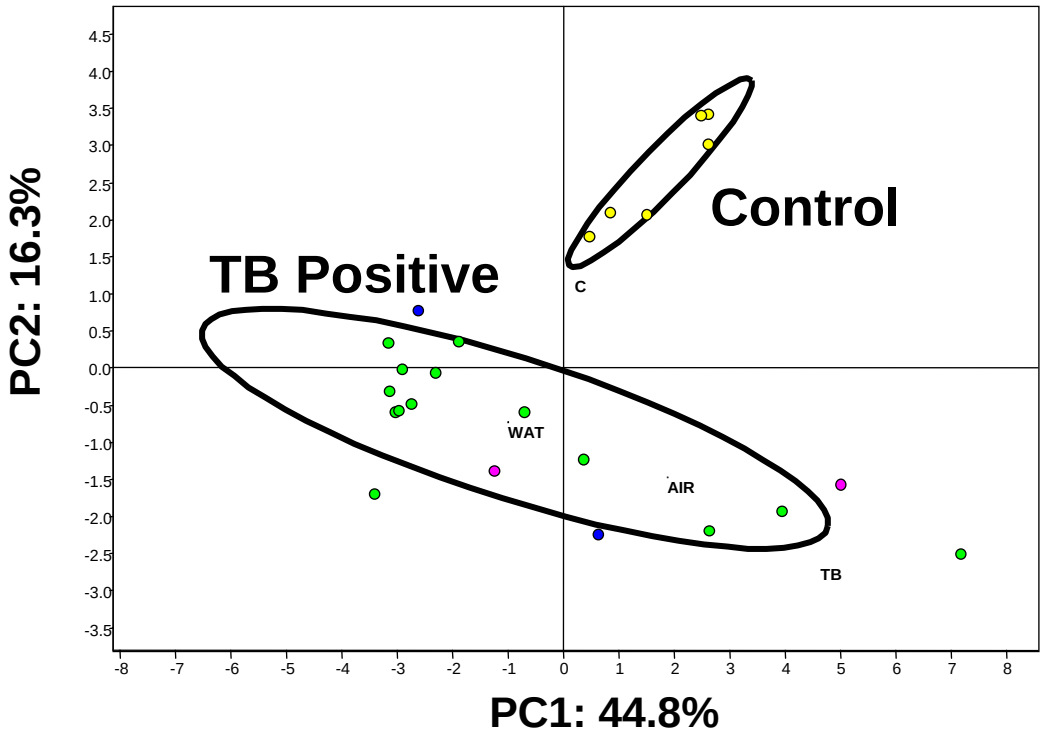
Detection of Mycobacterium tuberculosis

- Causative agent of tuberculosis, second-leading cause of death worldwide
- Potential for worldwide spread from countries where TB is endemic
- Difficult/long diagnosis
- Drug resistant strains!

Experiment with scary Picture of Big Pots of Tuberculosis with sampler headspace gas recovery apparatus for e-Nose sniffing

Autoclaved Bactec cultures of Mycobacterium tuberculosis clinical isolates discriminated from false positives with e-Nose data

[Stetter et al., ISOEN 2000, Brighton, England, July 20-24, 2000]



The Sense of Smell Has a Long History as a Medical Diagnostic Tool

- **Hippocrates: "In persons…with phthisis [tuberculosis], if the sputa…have a heavy smell when poured on coals, the case will prove fatal."(@ 400 BC)**
- **One of Five Techniques of traditional Chinese medicine is to examine the patient's odor.**
  - **Woodman and Fend, Electronic nose technology: potential applications in point of care clinical diagnosis and management," in C.P. Price et al. eds., Point of care testing, 2nd Ed. AACC press Washington DC 2004] and A.K. Pavlou and A.P Turner, "Sniffing out the truth: clinical diagnosis using electronic noses, Clin.Chem. Lab. Med 38:99-112, 2000.**
- **Microbiologists often used odor to discriminate among species of bacteria (Omelianski, 1923).**
  - M.W. Findlay, W.R. Penrose, **J.R. Stetter**, "Quality Classification of Grain Using a Sensor Array and Pattern Recognition", Analytical Chimica Acta, 284 [1993] 1-11.
- **Disease diagnosis appears possible:**
  - **DiNatale, et al., "Lung cancer identification by the analysis of breath by means of an array of non-selective gas sensors," Biosens. Bioelectron. 18: 1209-18, 2003.**
  - **Lin, et al., Application of the electronic nose for uremia diagnosis," Sensors and Actuators B76, 177-80, 2001**
  - **Chandiok et al., "Screening for bacterial vaginosis: a novel application of artificial nose technology. J.Clin.Pathol. 50:790, 1997.**
  - **Lai et al., "Identification of upper respiratory bacterial pathogens with the electronic nose." The Laryngoscope 112:975, 2002.**

Sensor Array / e-Nose methods are being developed for UTI, TB, STD, and other medical applications!
IT IS POSSIBLE TO DEVELOP ELECTRONIC NOSES FOR MEDIAL DIAGNOSIS!
A GREAT TOPIC FOR INTERNATIONAL SCIENTIFIC AND BUSINESS COOPERATION

Recent work in olfaction/Medicine

- **Nobel prize – October 2004; Linda Buck, Richard Axel; discovered long sought after family of odorant receptors and a model of the olfactory circuitry**
  - **human genome has 350 intact odorant receptor genes and other mammals more.**

- **Renaissance of Olfaction in Medicine**
  - "The medical profession…pays little attention to the lost art of diagnostic smelling…in this day of laboratory diagnosis..." Pope, 1928.
  - Today, there is a changing emphasis toward noninvasive and even self-administered diagnostic techniques, e.g., glucose strips, home pregnancy tests, …
  - Breath, urine, sweat, skin odor, saliva, sputum, all have diagnostic potential.

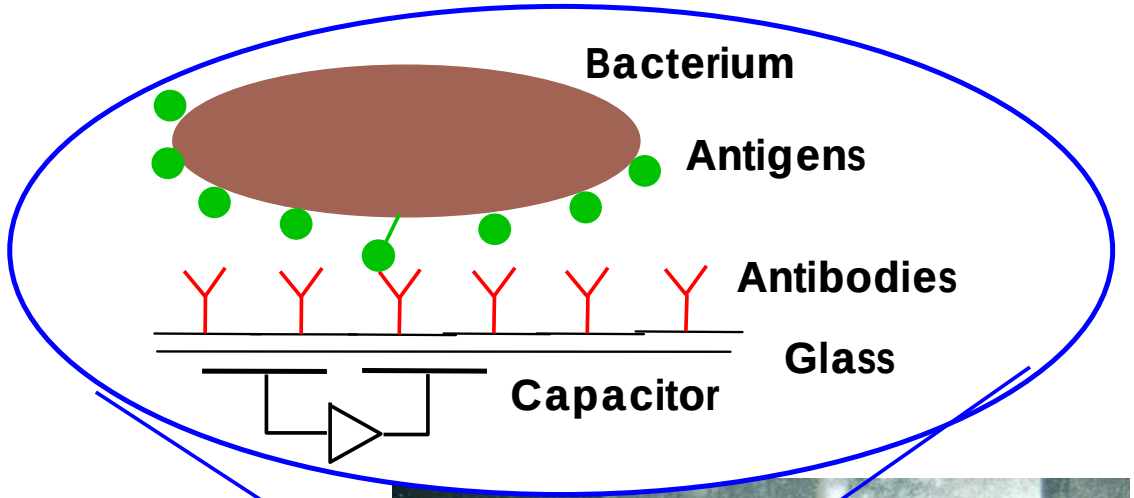
Imaging - multidimensional data used to produce a Visual representation for analytical purpose

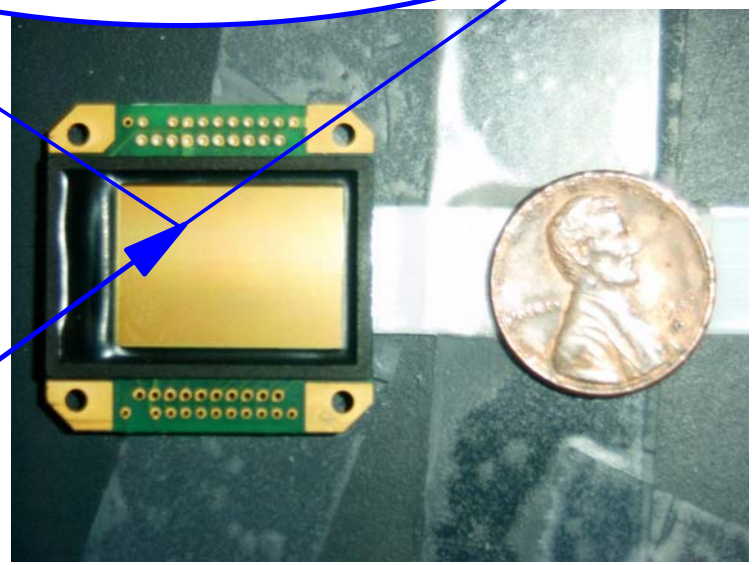
[what? How much? Where to? Where from?]

- Space - size, shape [x, y, z] - microscope.
- Time - reaction or transition; over time - melting to binding.
- Chemical - specific reagents - adsorption, partition, ionization, emission/absorption.
- Bio-chemical - whole cell, affinity, enzyme, antibody.

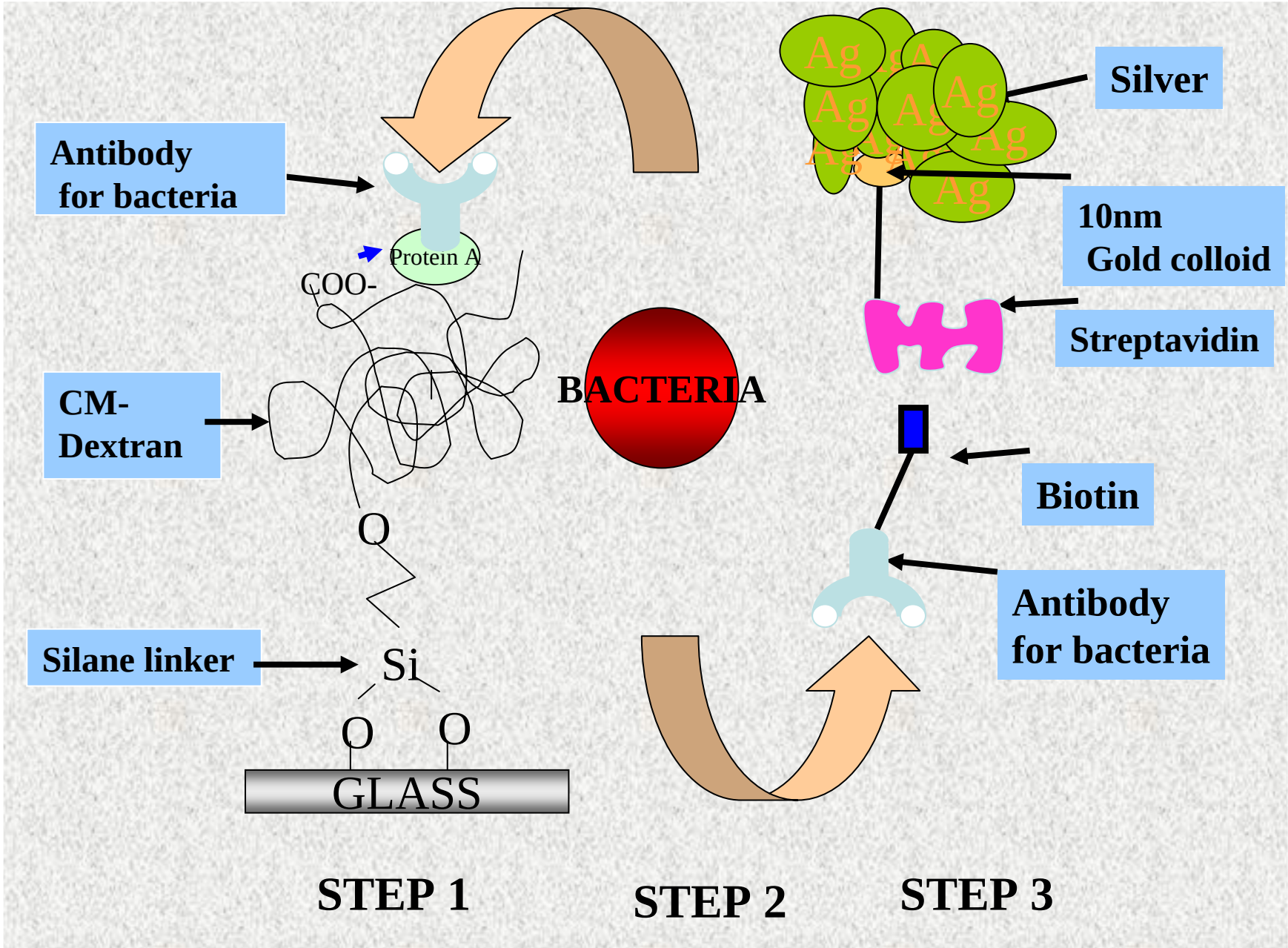
e-Biosensor
Electronic Imaging Sensor Array

- Chip has 93,184 sensors
- 1 x 1.5 cm
- Operates on PC
- Reads 25x/sec
- Provides image of surface state!





Expanded view of one of 93,184 pixels



Making a biosensor on a transducer surface!

Photo Gallery: Electronic Sensor Array for molecules to particles!

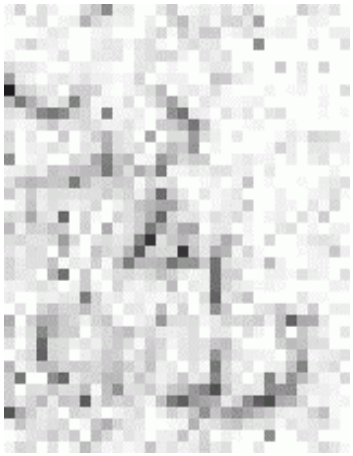
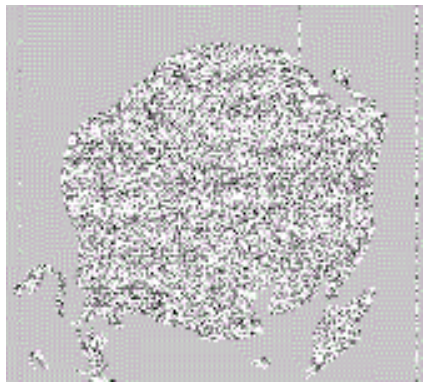
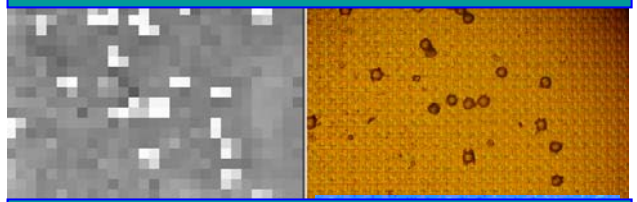


Image of living organisms
Nematodes in water drop

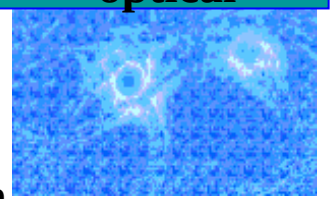


Live Chicken embryo cells

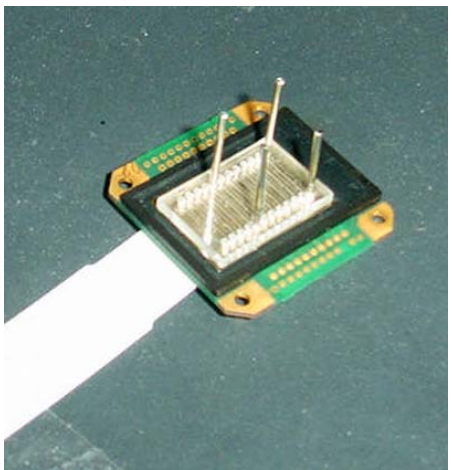
20 um Pecan pollen

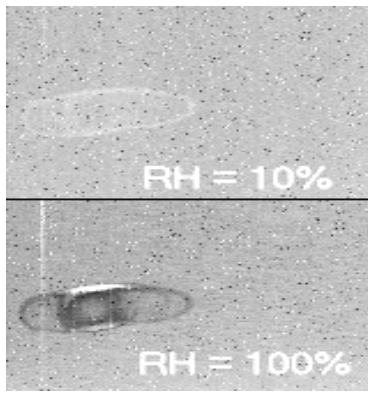


Chip ---------- optical

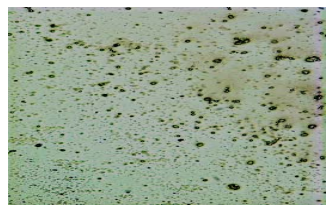


Sodium Phosphate crystals





Gas sensor



Anti-AP Positive

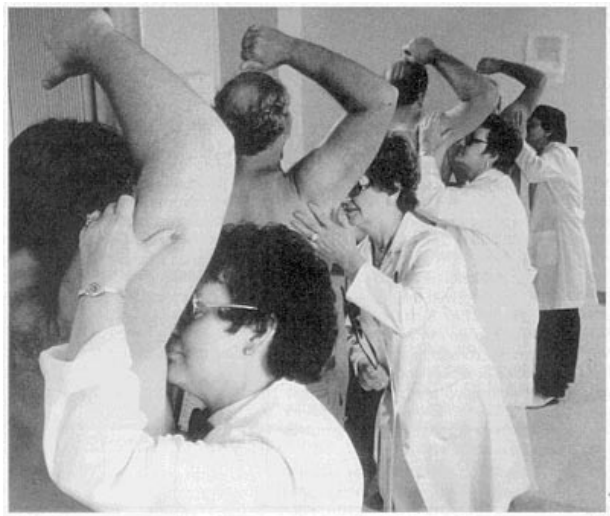
Anti-AP Control

large molecule proteins!

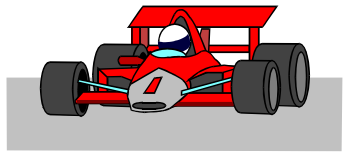
- ChemArray chip microfluidics allows 10 simultaneous operations.

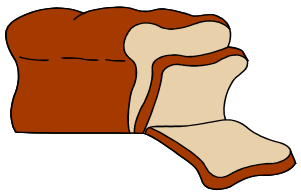
Electronic Nose: Advantages.

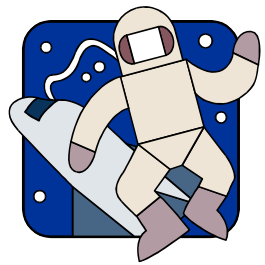
- **Human ‘sniffers’?**
  - Odor panels are expensive
  - Individuals vary, daily.
  - Hazardous Chemicals harm people
  - Operate for short periods of time.
- **Conventional instrumentation?**
  - Large, slow, and costly.
- ***E-Nose***
  - ***low power, cost, size possible***
  - ***can address problems refractory to other analytical approaches.***



Many Uses of Electronic Noses







- Automotive
- Food safety
- Medicine
- Emergency response
- Military and space
- Environmental & IAQ

Why do we need it?

Ans. Pervasive Situational Awareness requires sensors & instruments [hardware/software]

$4B Sensor Market By 2006*

*Fredonia Group

Why do we need sensing?
Modern Cities and Situational Awareness

- Modern cities are bastions of culture, education, commerce, recreation, and living.
- Modern cities are challenged with transportation, communications, healthcare, and lifestyle demands including clean air, potable water, food, services, and shelter.
- Safety and security [man-made/natural] have become a global concern and traditional defense and response is not adequate.
- Science & Technology plays a major role in countering terrorism, advanced services, & defense to make a city safe.

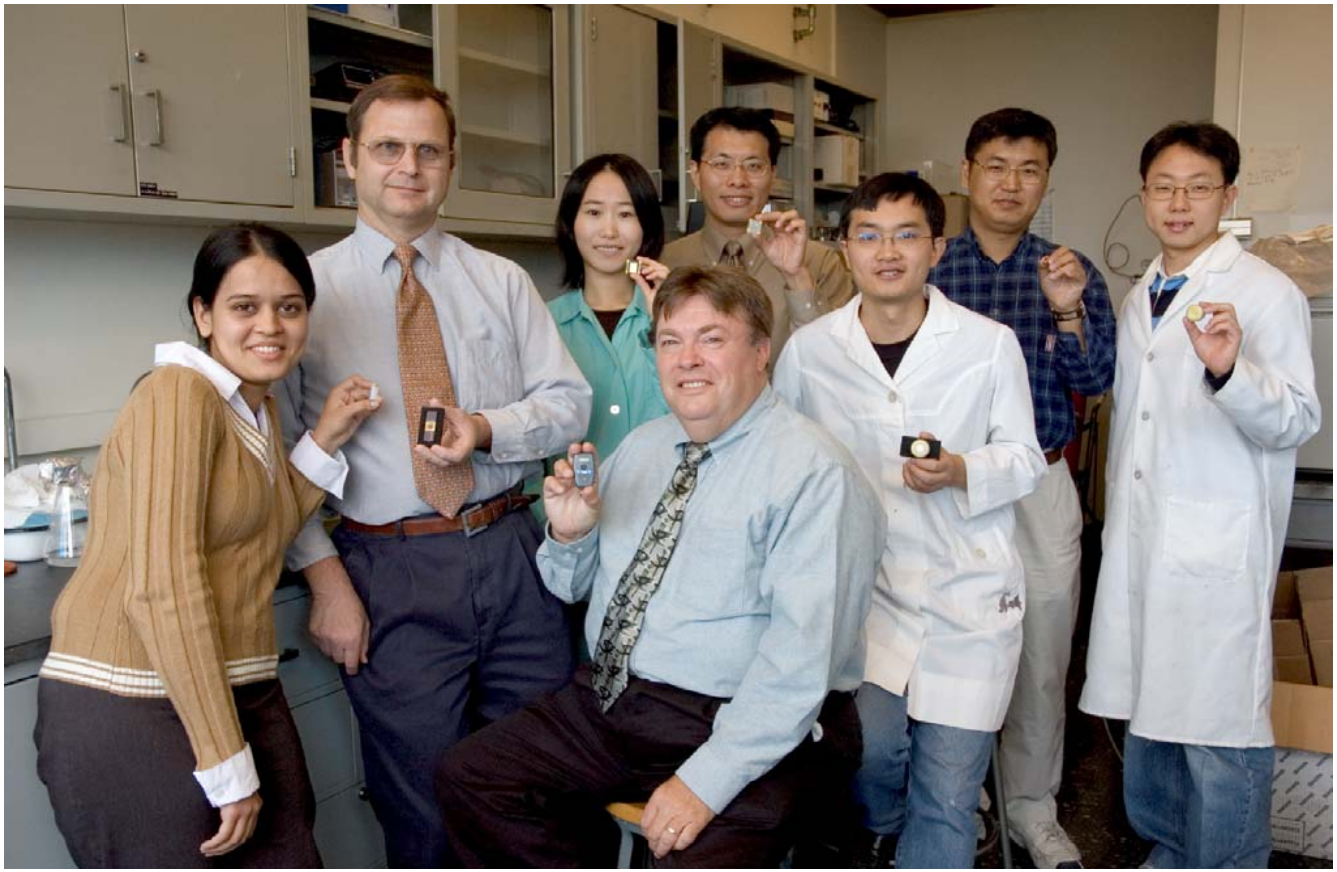
1993 Kameido, Tokyo, Japan Anthrax release

- **A safe, secure, aware city will be the preferred place for business, commerce, recreation, and living.**

Tsunami, Dec.2004, New York Times

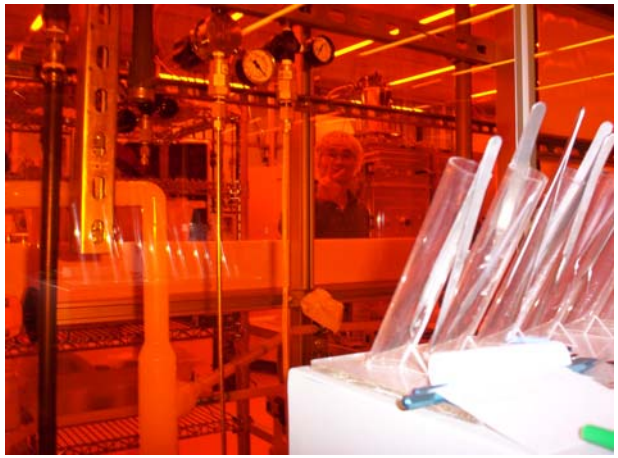
Illinois Institute of Technology Sensor Research Group

IIT International Center for Sensor Science and Engineering.



Prof. Joseph R. Stetter's IIT Sensor Research Group [December 2004]. In front, Dr. Stetter, Director of the IIT International Center for Sensor Science and Engineering, holding the world's smallest toxic gas monitor/dosimeter developed with a new nano-technology-enabled sensor that is ultra-low power, small/thin, highly sensitive & selective. Back row from left, Margee Shah with chip sensor, Dr. William Buttner, Associate Director of the SRG, with carbon nanotube sensor, Jenna Zhang with ChemArray chip biosensor for single cell & bio-toxin detection, Dr. Jacob Zhang with weathering chamber sensor, Ming Ni with hydrogen sensor for fuel cell applications, Dr. Saeweon Roh with Nano-structured-carbon-composite sensor, and Guh Zhang with electrochemical sensor for toxics, explosives, and mass market applications. [Missing from photo are graduate students Yen-Te Chao and Kapil Gupta, and undergraduate student Calvin Moy]. IIT, Chicago, IL 60616 USA

Microsystems Innovation Center {µSIC}



Product & Process Development

Micro-Devices, Nano-Sensors

Value Creation & Technology Transfer

Development of High Value Solutions and Innovations:

MEMS, Vacuum Microelectronics, Sensors.

New materials in micro- and nano-dimensions.

Sensor Arrays, Artificial Senses, Awareness, Intelligence

ELECTRONIC- NOSE, TONGUE, EYE, PANCREAS, EAR, TOUCH

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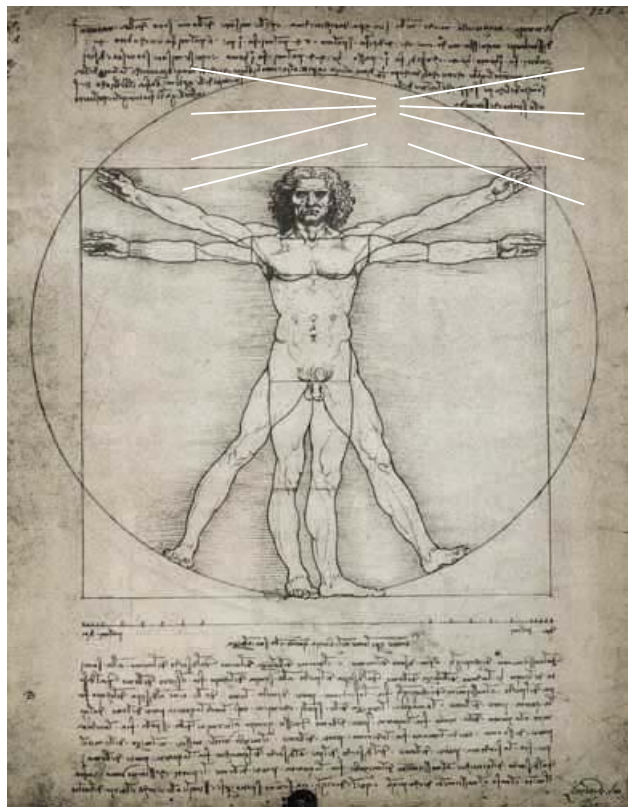
- Future Sensors Systems:
  - Provide - Awareness, safety, health, security – {Artificial Nose, Eyes, Ears, Immune systems, Touch, …}
  - Promote international business cooperation
  - Leverage international scientific meetings
    - Transducer's 05 Seoul
    - ISOEN 2005, Portugal
    - Hilton head, IEEE, …
    - ECS – Quebec, LA, Cancun, Paris, Hawaii



FINIS