A Computing Environment for Spatial Analysis and Visualization of IC Manufacturing Data

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A Computing Environment

Computing in the sense of J. M. Chambers (1998) *computing with data*: An environment for the

- Organization
- Analysis
- Presentation

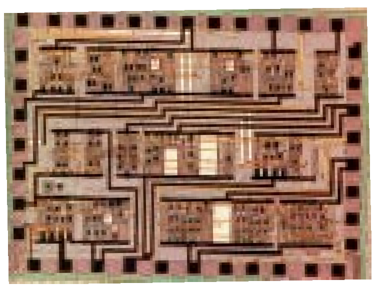
of data from IC manufacturing.

Outline

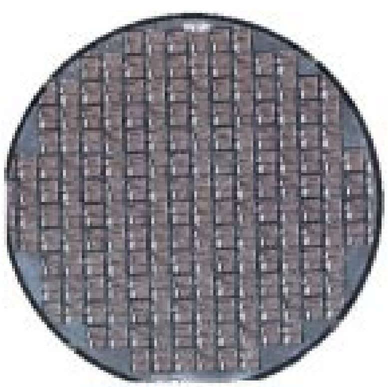
1. IC manufacturing and its data
2. Functionality in the current implementation
3. Extensions for distributed computing
4. Conclusions

Integrated Circuit Manufacturing

Long, complex manufacturing. Fabrication requires hundreds of steps and typically lasts up to several weeks.



Multiple layers of minute electronics are built sequentially.

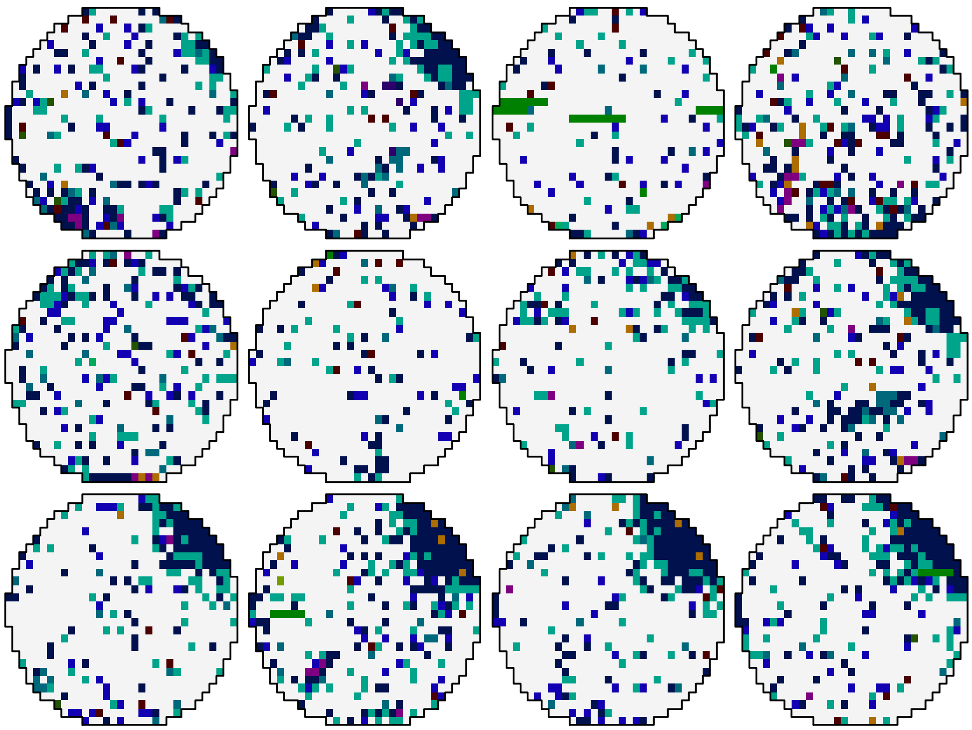


Hundred of IC's are fabricated simultaneously on a wafer. Wafers are processed in *lots*.

Production. Thousands of wafers being produced at any one time. Many technologies and types of products.

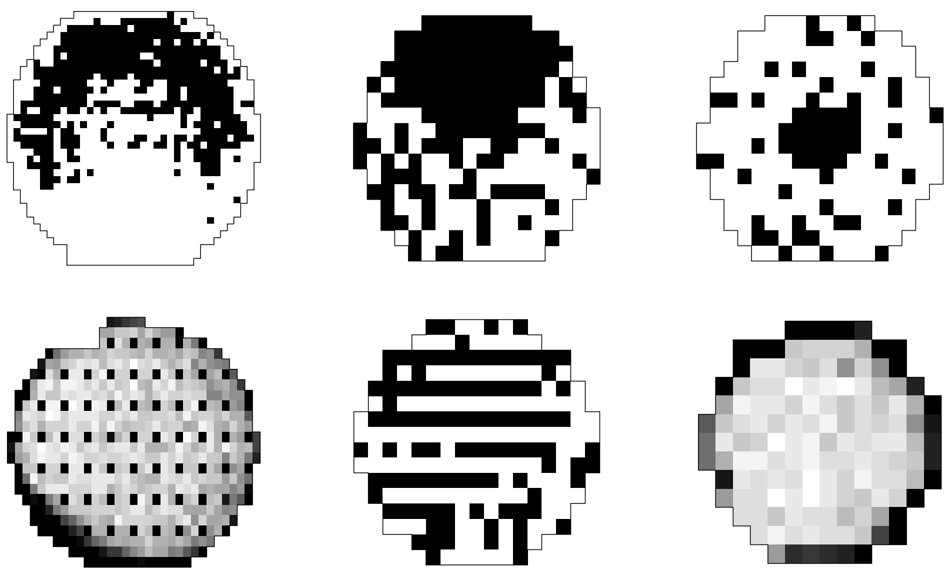
Wafer Map Data

Probe Test Data



IC Manufacturing

- Vast amounts of data for monitoring and control;
- highly structured and spatial data are ubiquitous;
- countless processes leave spatial "signatures" on the product;



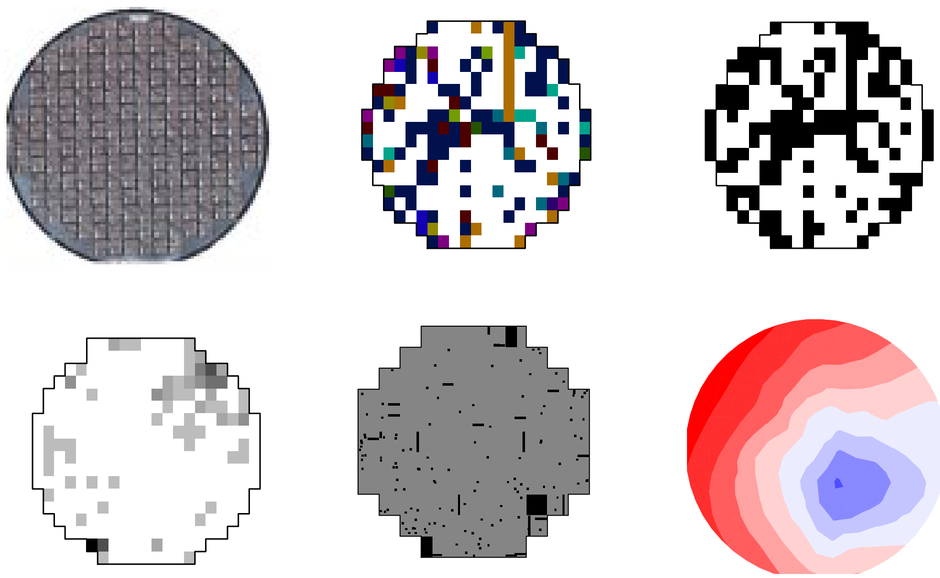
- need for extending Shewhart principles to spatial processes;
- Need for making spatial data analysis common practice.

IC Manufacturing

The improvement of IC manufacturing processes requires

- Understanding and insights of spatial processes
- extensions to existing statistical methodology
- new statistical methodology
- a computing environment for implementing the above

Wafer Map Data



- Failure categories in addition to good/bad
- particle locations, size, and counts
- memory arrays bit failures
- fully continuous “parametric” data
- varying degrees of spatial sampling
- distributed over databases

A Computing Environment

Some functionality

- Exploratory data analysis and visualization
- Spatial process monitoring
- Identification spatial patterns and defect clustering
- Yield modeling
- Parametric modeling and classification
- Spatial DOE
- Electric tests and defect-type data

A Computing Environment

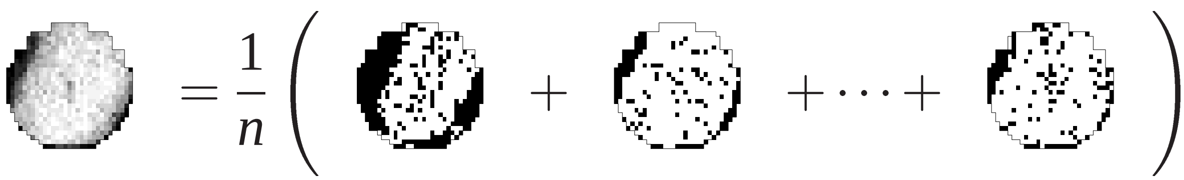
The base language **S** provides

- means to express advance computations
- a powerful statistical and graphical engine
- an object-based system to encapsulate spatial data and their computations
- an extensible environment.

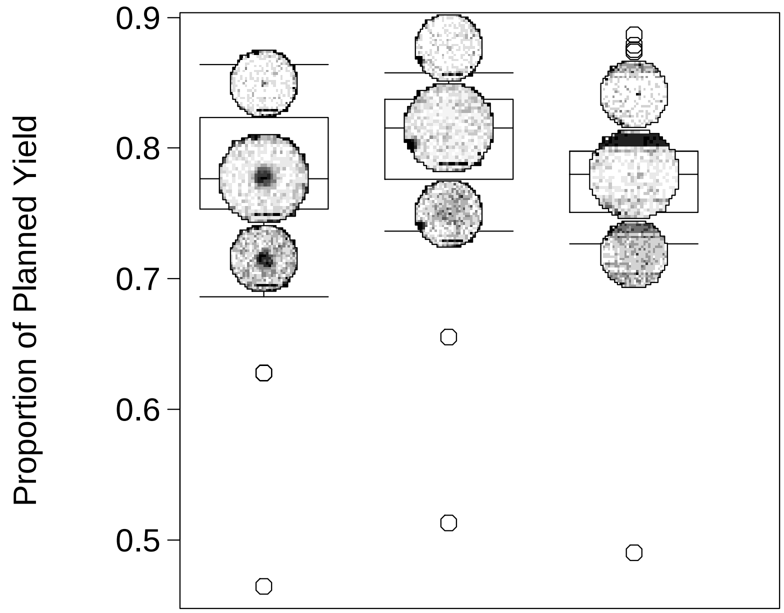
The Current Environment

Simple extensions to common graphical displays by superposing wafer glyphs

- Composite maps (mean)

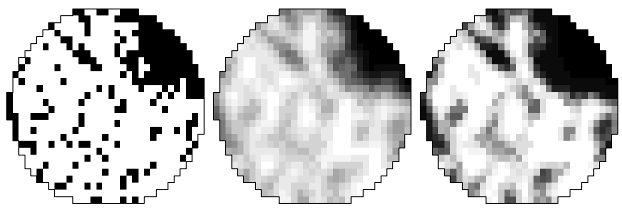


- Boxplots

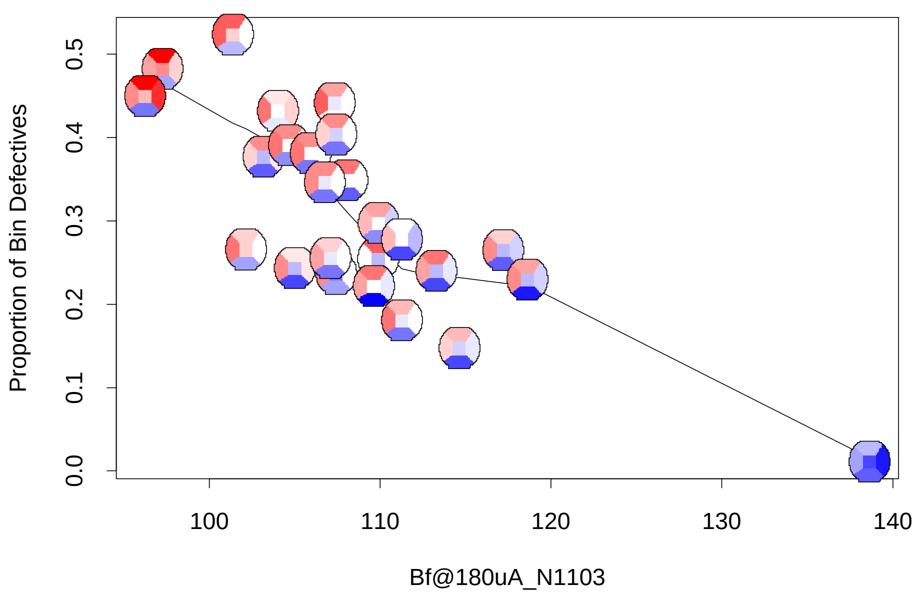


The Current Environment

- Smoothing



- Scatterplots



Wafer Maps as Multivariate Data

We may readily employ many multivariate techniques:

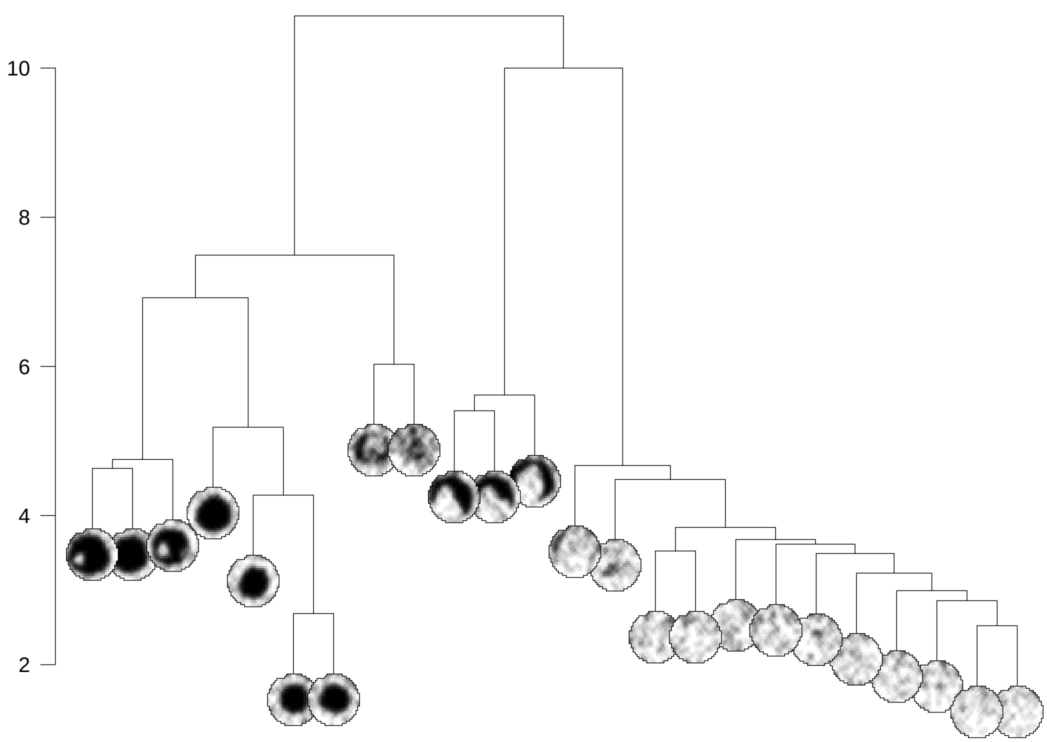
- Regression and anova models
- Loess and other smoothing techniques
- Clustering techniques
- Generalized Linear Models
- Principle components
- Classification and regression trees

For instance, hierarchical clustering algorithms are quite useful for finding groups of similar wafers.

Finding Groups of Similar Wafers

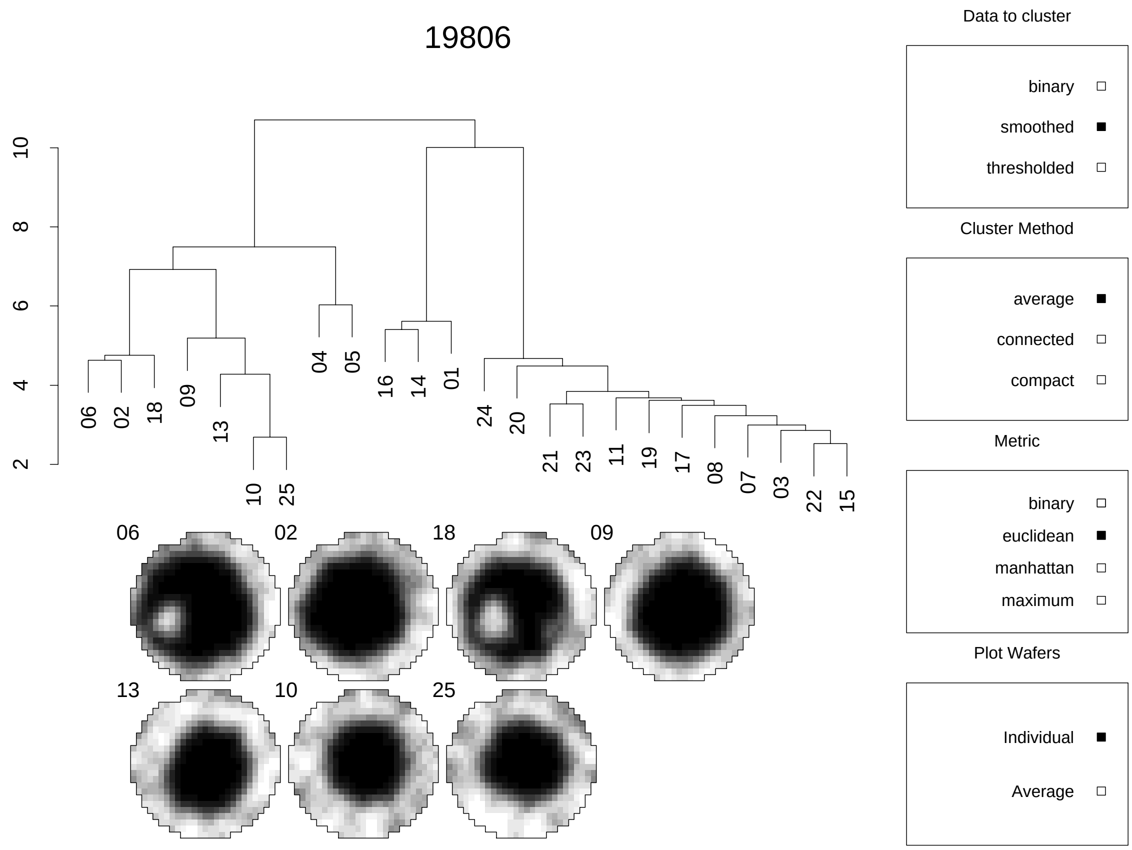
We can exploit the above idea to look for groups of wafers with similar clustered defects.

- Smooth binary data
- Hierarchical clustering (Kaufman & Rousseeuw, 1990)

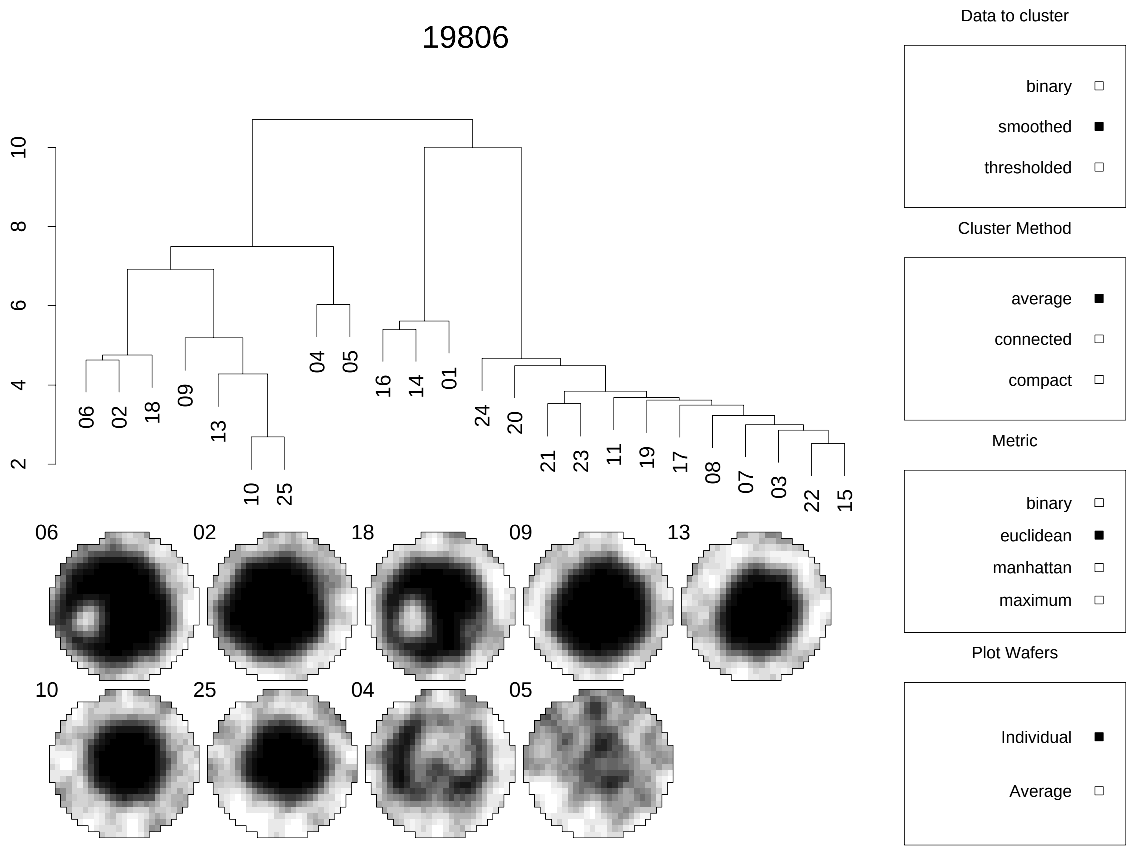


Data Browsers

Interactive graphics for exploring groupings through "linked plots"



Data Browsers



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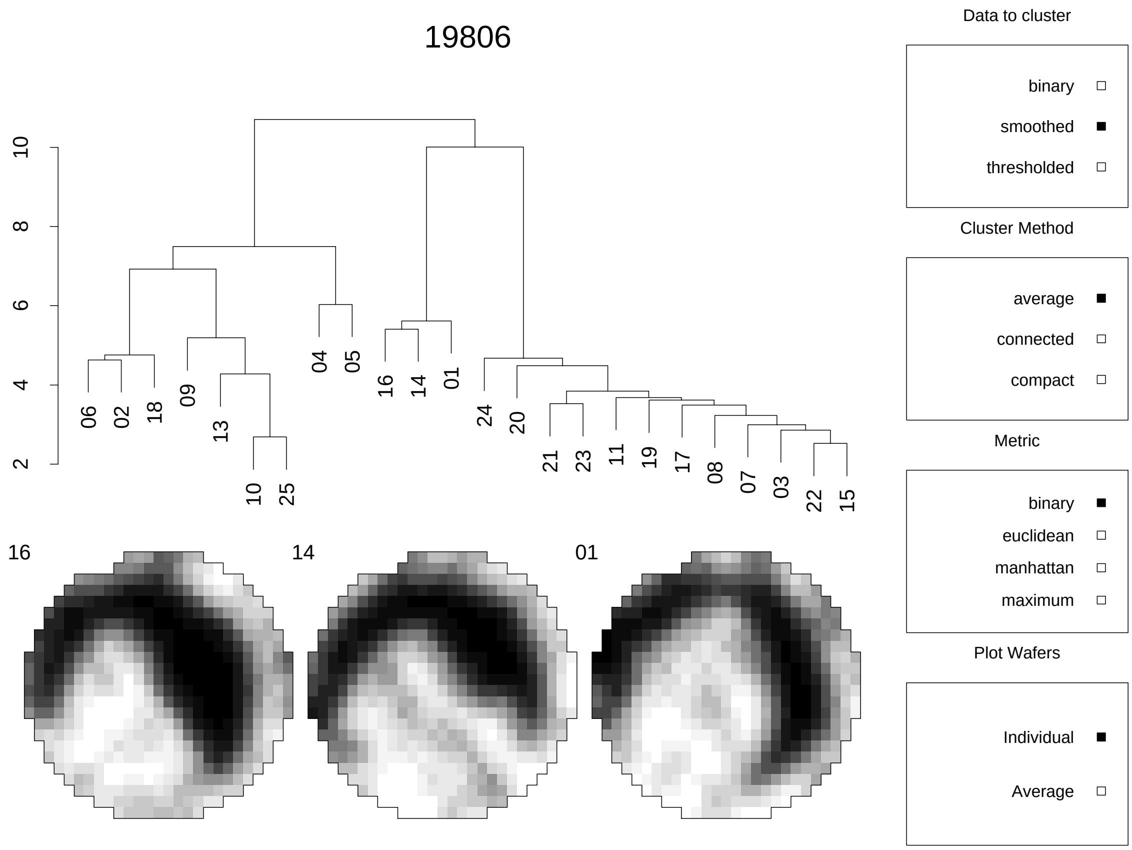
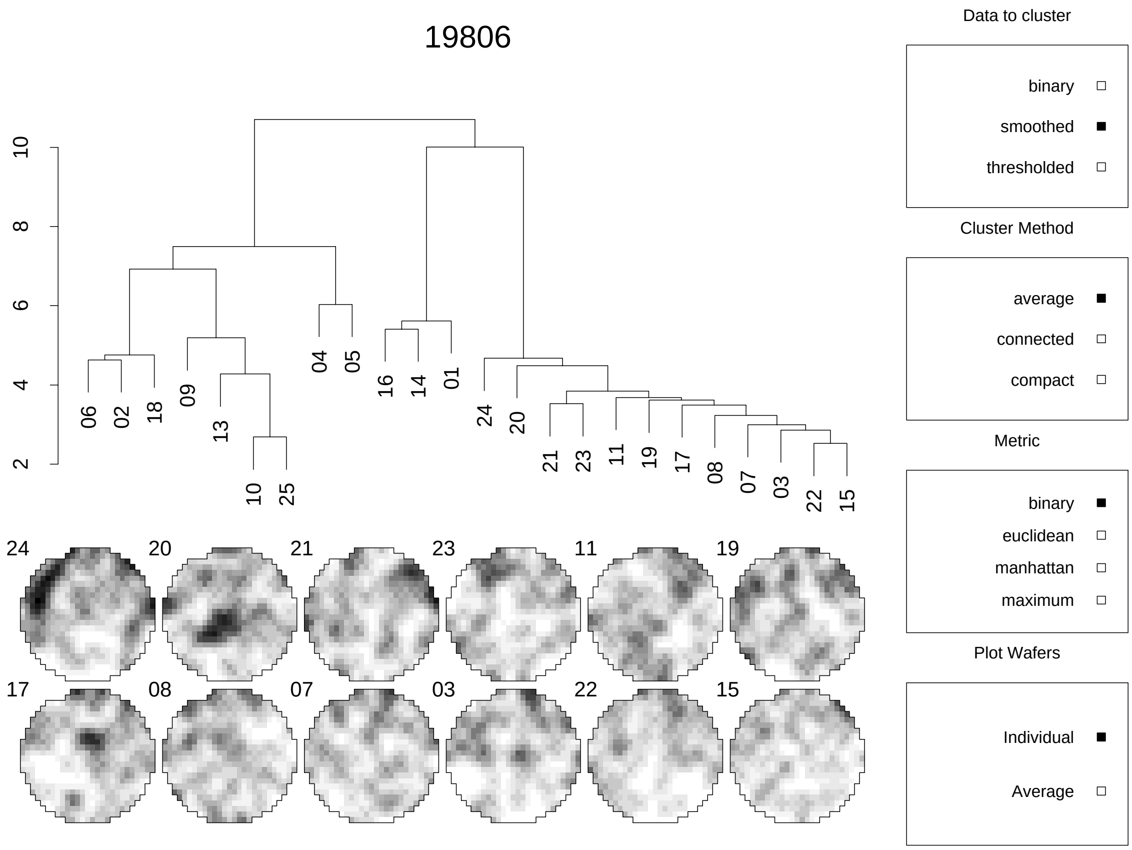


Data Browsers



There is a need for better integration of graphics with the host windowing system.

Shewhart's Principles and IC Manufacturing

The principle of *random* and *assignable* causes needs to be articulated in terms of spatial processes.

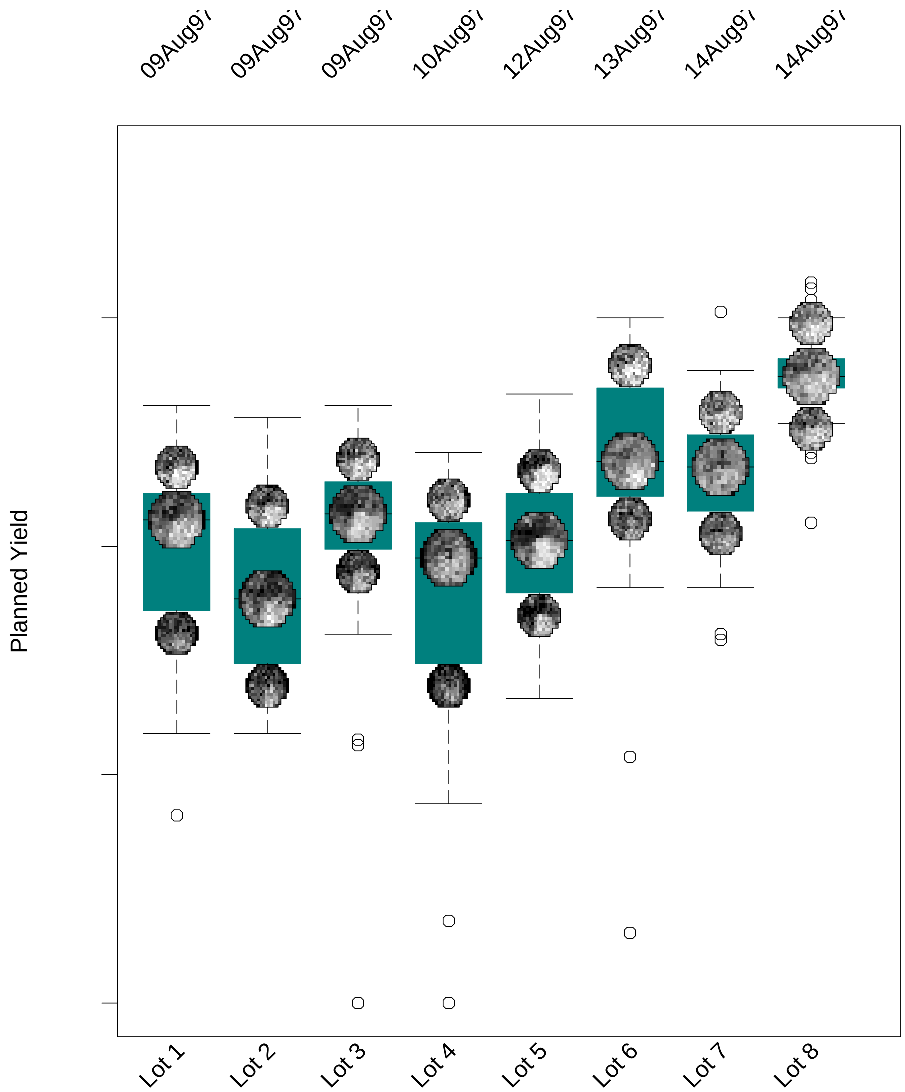
Monitoring. To spatially separate "assignable" from "random" causes.

Diagnosis. To ferret out factors that spatially impact production.

And the application of SPC in its broadest sense.

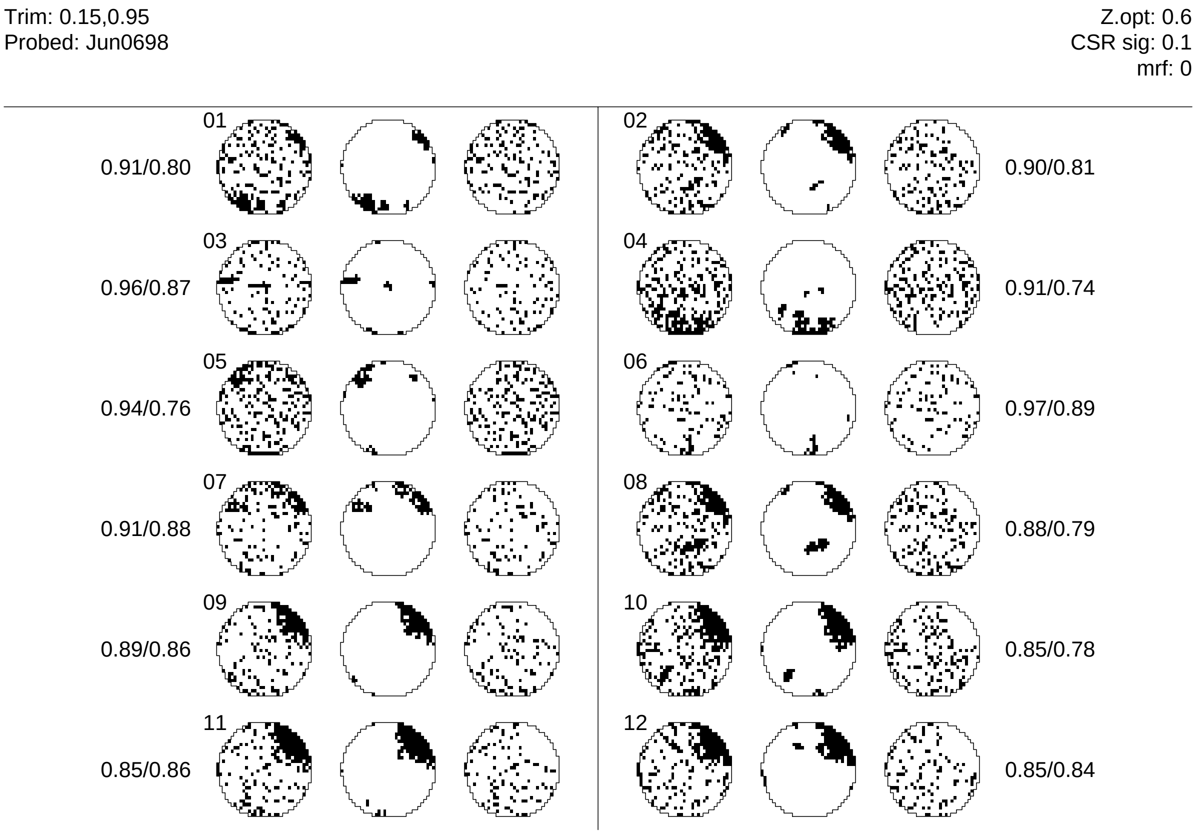
Monitoring Production

From Simple graphical superposition of wafer glyphs...



Monitoring Spatial and Random Defects

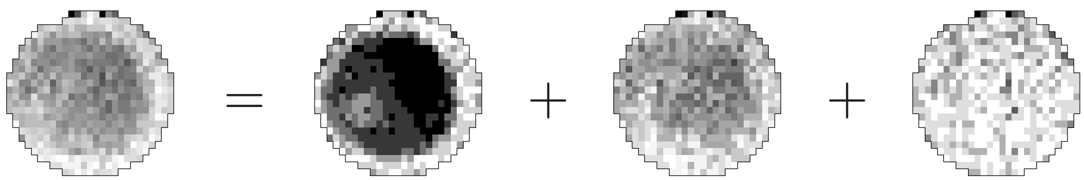
To more computational intensive wafer-wise yield decomposition



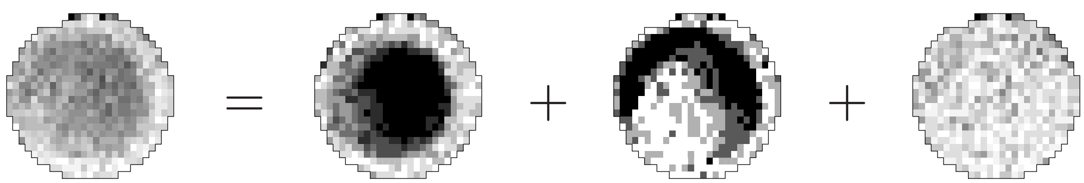
from which we can track both the Y_0 and D_0.

Composites may Mask Patterns

Lower/Upper Quartiles:

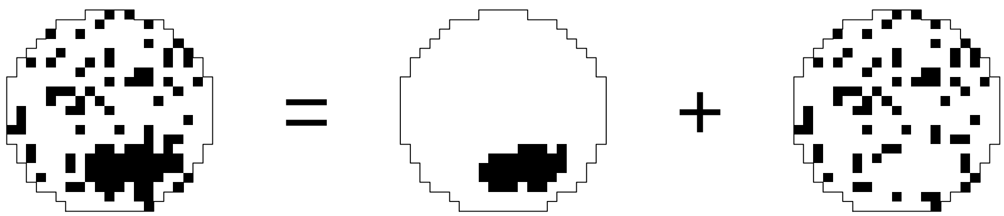


Spatial Patterns:



Patterns or Noise?

Modeling yield loss as a superposition of two destructive mechanisms.



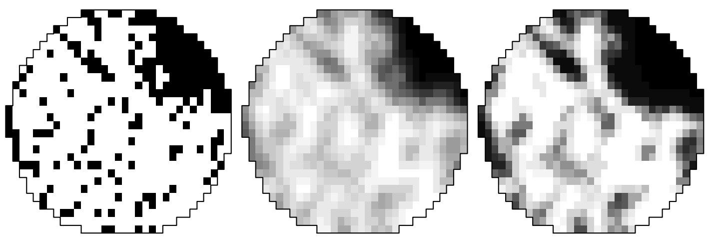
- Large area defects are process-related (by and large).
- Small area defects are typically random particle defects.

Compute local averages as a means to enhance local features.

Patterns or Noise?

Untangling clustered from random defects.

Smoothing: compute local proportions

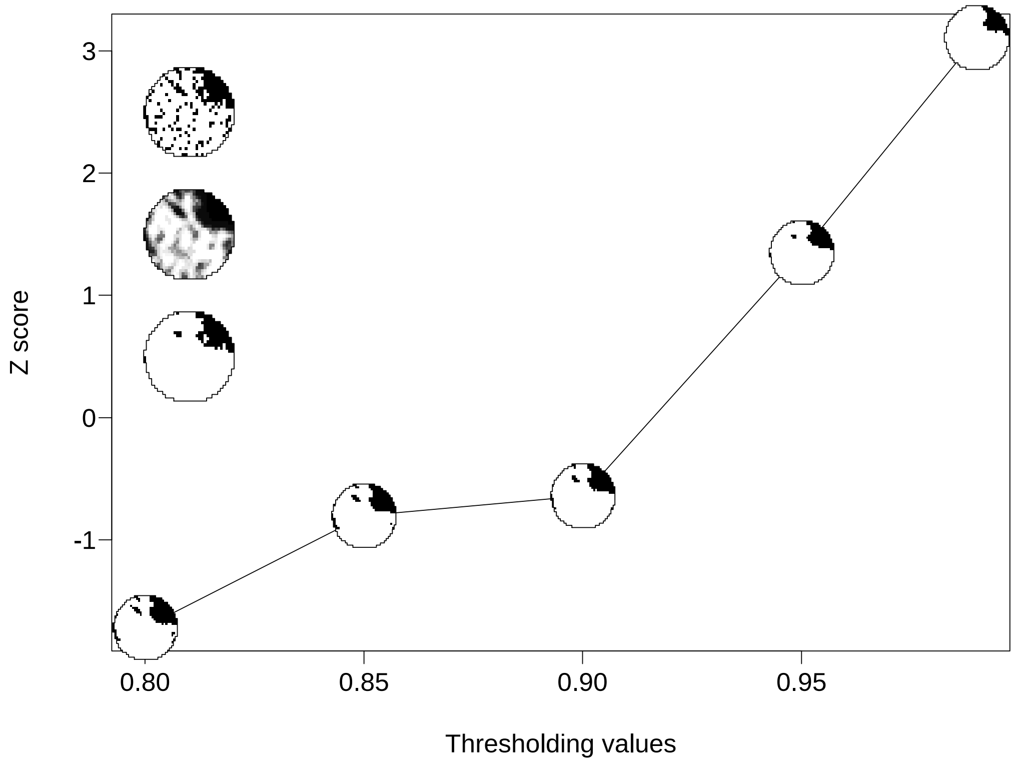


- Define a neighborhood and weights to compute local weighted averages.
- Transform smoothed wafers

Thresholding: partition the wafer into clustered and random areas.

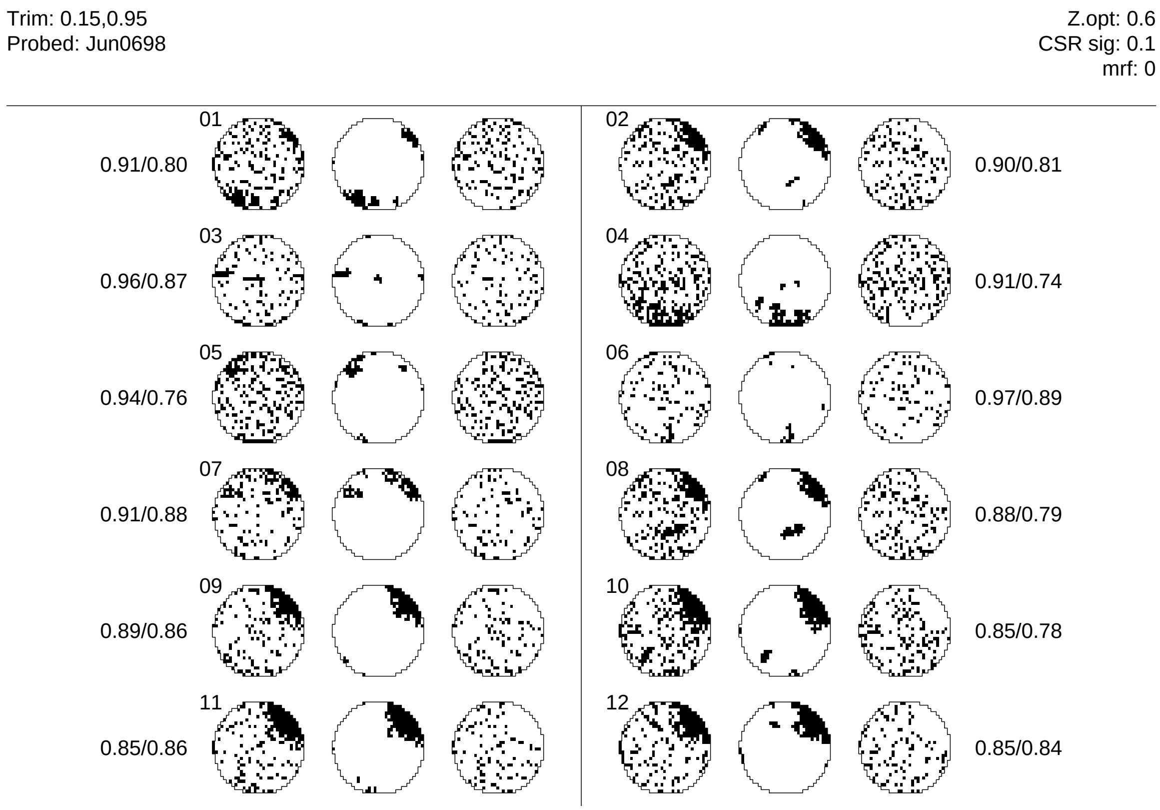
Patterns or Noise?

Sequential procedure for detecting threshold:

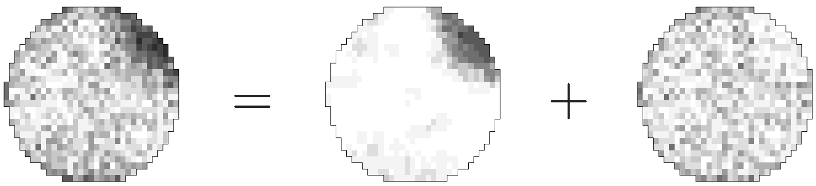


Separating Clustered from Random Defects

We thus can factor yield into its spatial and random components:

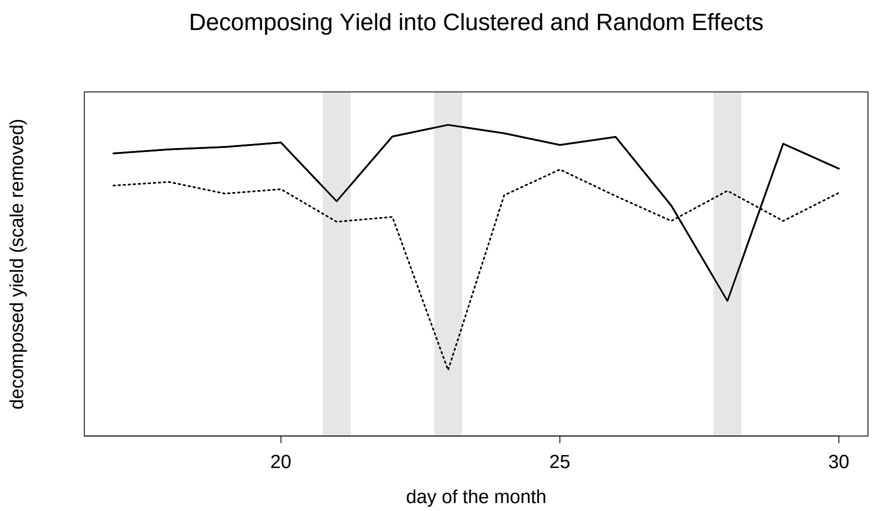


The composites for the data, and its clustered and random component are

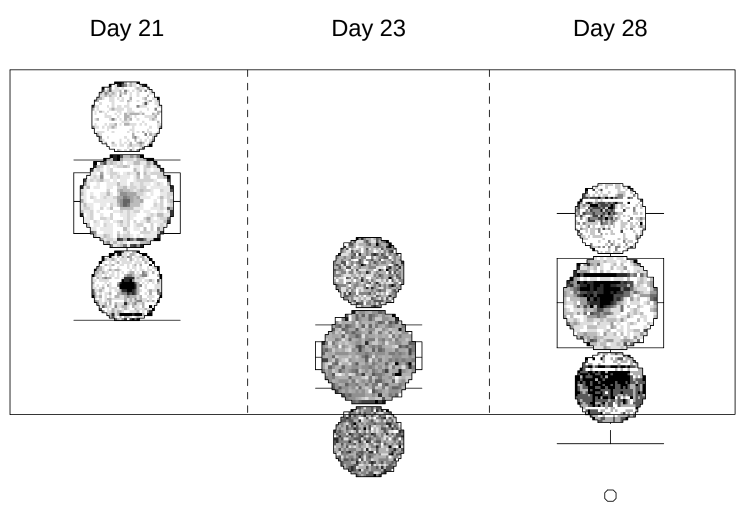


Monitoring Spatial and Random Defects

Assignable causes may or may not be spatial



The lot in the middle shows a high intensity random component as assignable cause



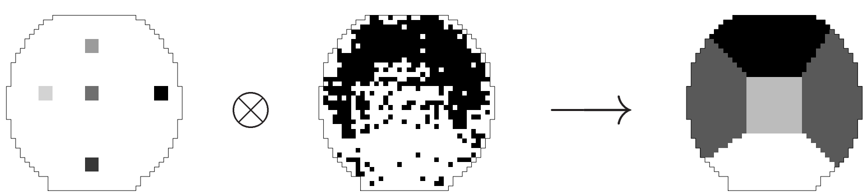
SPC in its Broadest Sense

Identification of problems and their likely sources through data analysis

Example: Tools for diagnosing a “failing“ lot:

- In-line data (cosmetic, “positrack”) wasn’t helpful.
- IV parametric data did provide clues.

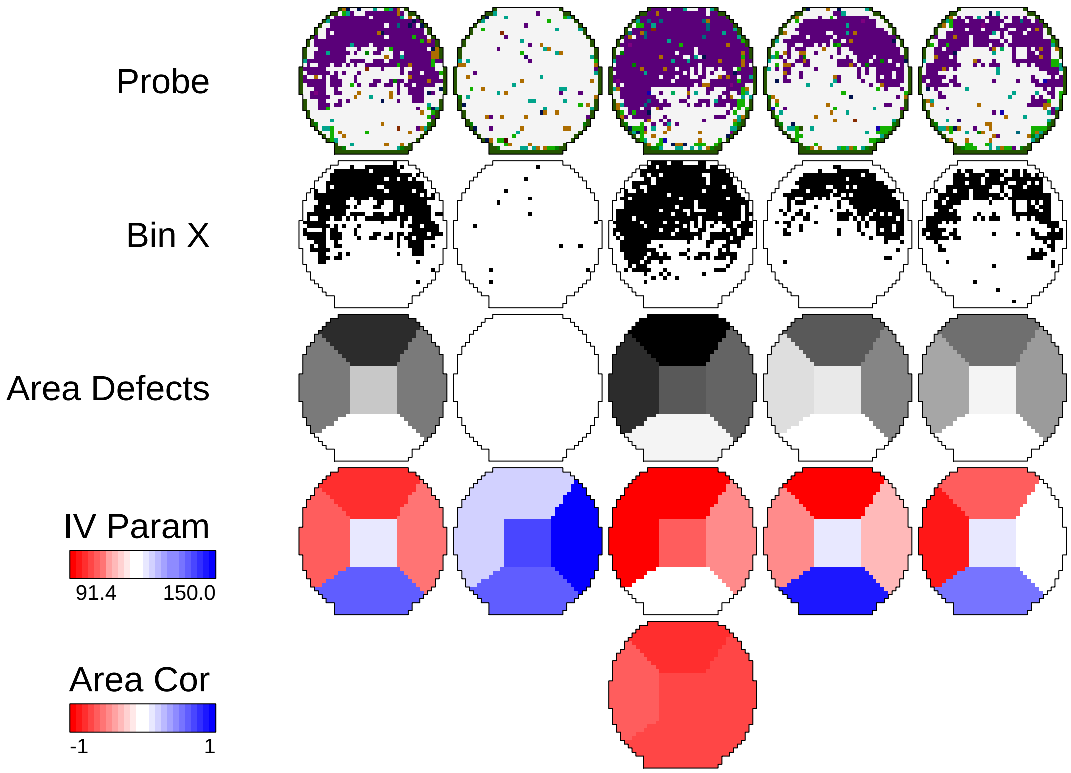
IV spatial sampling defines areas within wafers.



Need to easily merge probe and IV maps to properly account for spatial variation.

SPC in its Broadest Sense

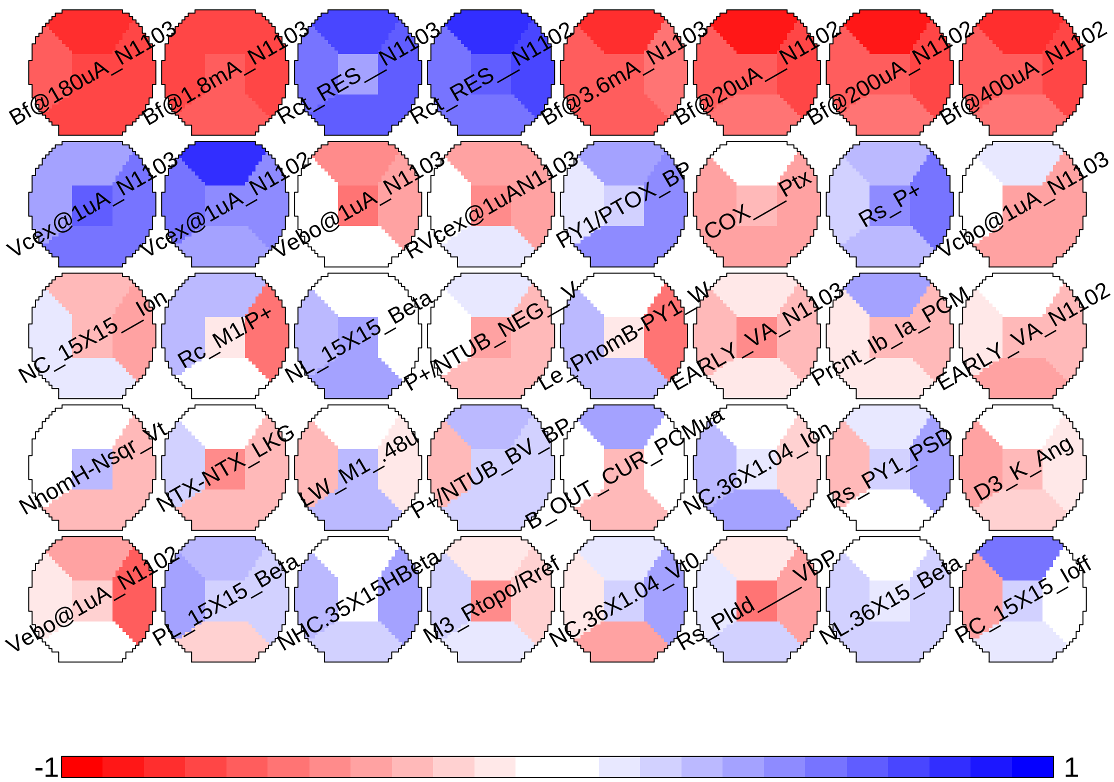
We compute area yields and match these to IV data to compute area correlations (Pearson).



This is a simple tessellation of the wafer map, but other partitions may be constructed.

SPC in its Broadest Sense

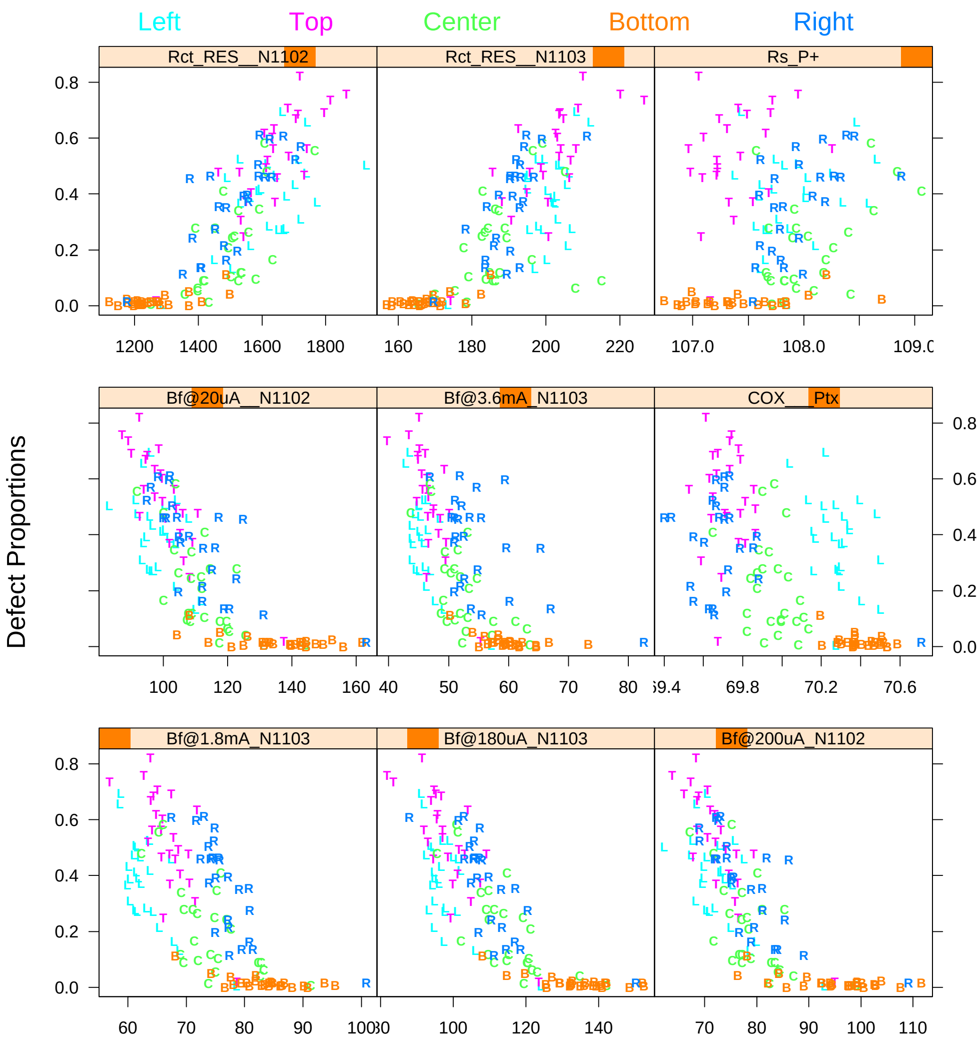
Top parametric area correlations



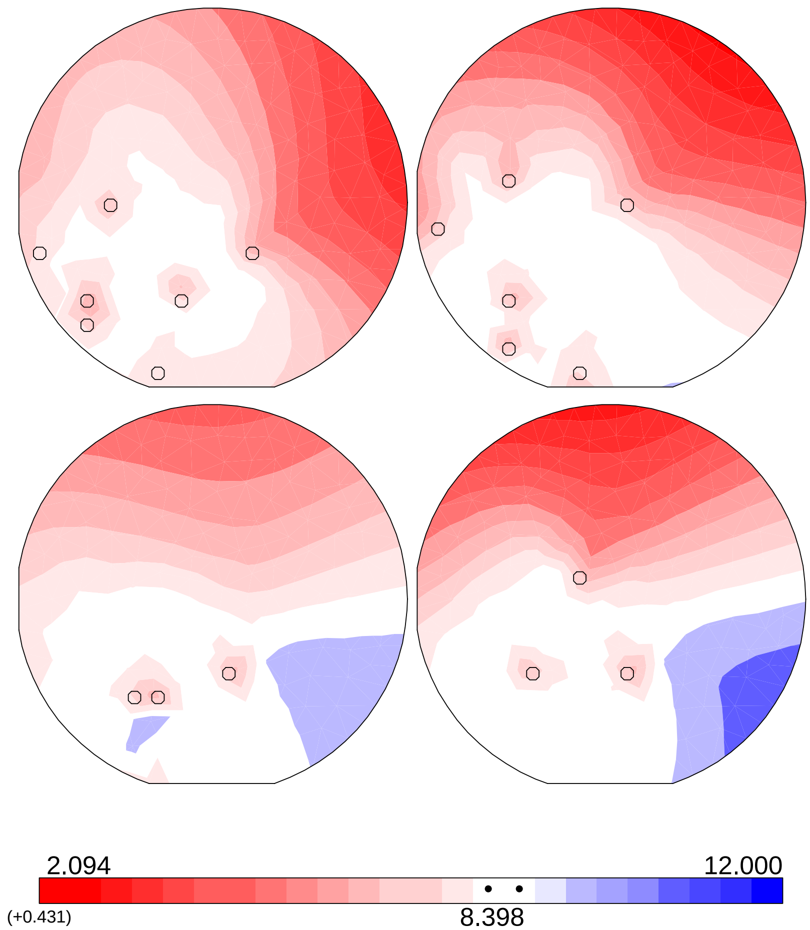
More flexible models than Pearson’s correlations may be computed within wafer areas.

SPC in its Broadest Sense

Full Details on most likely IV parameters



E-tests and Defect-type data



- E-test as a canvas
- Defect-type data on top

Extensions for Distributed Computing

There is a need for

- Access to distributed data
- Provide analyses to client applications
- Better interactive graphics
- Additional user-interfaces

Build on recent advances in distributed statistical computing

- CORBA
- S-Java interface and JDBC

Distributed Data

Multiple data bases, different levels of aggregation

- Probe testing
- Product work flow
- Process control
- SPC
- Facilities management
- Particles, bitmaps

Current interface is through text files (simple, robust, but labor-intensive).

External Application

- Various reporting systems
- Web applets
- Real-time monitors
- Different platforms and languages
- Complex communications (e.g., sockets, RPC)

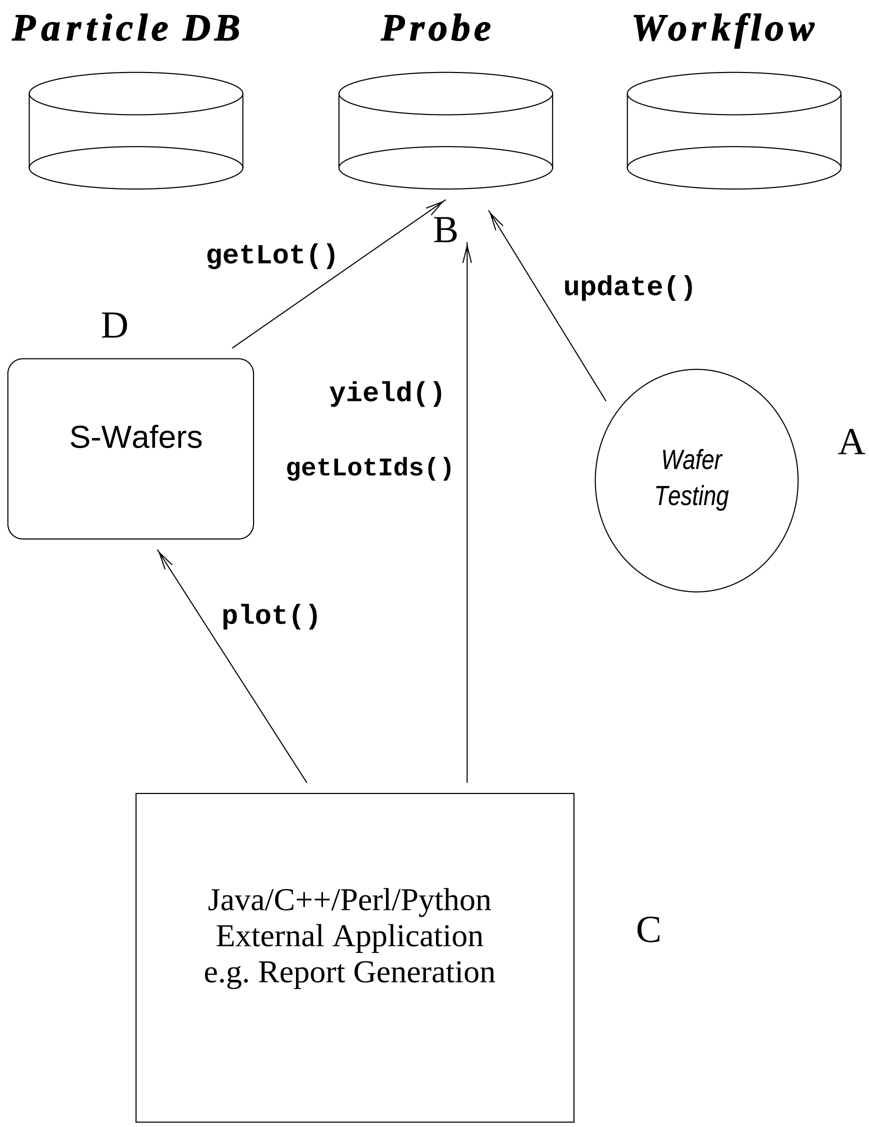
Clients, Servers, and Middleware

S-WAFERS as a multi-server over a CORBA bus providing

- visualization
- CSR and yield spatial factorization
- Spatial monitoring

These services are provided to clients independently of platform, language, and location where server and client reside.

A CORBA Architecture



Conclusions

- IC manufacturing involves many complex processes that require large amounts of highly-structured and spatial data for monitor and control.
- We've extended existing statistical methodology to fully exploit the spatial information in these data.
- S-WAFERS is a computing environment tailored for the spatial analysis of IC data that provides tools for visualization, spatial monitoring, yield modeling, and other tools.
- We're facing the challenge of large, de-centralized databases and provisioning of spatial analysis to client applications through distributed computing based on CORBA.