• Defects on semiconductor wafers
  – Spatial defect patterns contain useful information about issues during integrated circuit fabrication
  – Promptly detecting abnormal wafers is an important way to increase yield and product quality

• Objective
  – Develop an algorithm for detecting abnormal DRAM wafers more accurately in semiconductor manufacturing

• Binarized FBT maps
  – A generalized joint count-based statistics
    \[ T^{(k)}(g) = p^{(k)} c^{(k)}(g) + (1 - p^{(k)}) c_{11}^{(k)}(g) \]
  – The test statistic corresponding to the spatial lag \( g \)
    \[ Z_{T^{(k)}}(g) = \frac{T^{(k)}(g) - c^{(k)}(g)p^{(k)}(1 - p^{(k)})}{\sqrt{c^{(k)}(g)p^{(k)}(1 - p^{(k))}^2}} \sim N(0, 1) \]

  – The original FBT value of \( t \)-th functional chip of \( k \)-th FBT map
    \[ \hat{f}_{h_{h}}^{(k)}(u) = \frac{1}{n f_{h_{h}}} \sum_{i=1}^{n f_{h_{h}}} \left( \frac{u^{(k)} - u^{(k)}}{h^{(k)}} \right)^2 \]

• Spatial Local Denoising
  – Case 1) De-Noising the Interior of the Binarized FBT Map
    \[ R^{(k)}(i, j) = \frac{1}{l^2} \sum_{m=-l}^{l} \sum_{n=-l}^{l} x^{(k)}(i + m, j + n) \]
  – Case 2) De-Noising the Edges of the Binarized FBT Map
    \[ R^{(k)}(i, j) = \frac{1}{N(i, j)} \sum_{m=-l}^{l} \sum_{n=-l}^{l} x^{(k)}(i + m, j + n) \]

• Step-down Randomness Test
  – Test statistics and Control limits
    \[ Z_1 = \frac{y_r^{(1)}}{T^2_{1}} - \frac{y_r^{(1)}}{y_r^{(1)}} \quad CL_1 = \frac{(n - r)^2}{(n - 1)} \quad F_{\alpha_1}(r, n - r) \]
    \[ Z_k = \frac{T^2_k - T^2_{k-1}}{1 + T^2_{k-1}/(n - 1)} \quad CL_k = \frac{(n - 1)^2}{(n - kr)} \quad F_{\alpha_k}(r, n - kr), k = 2, 3, \ldots, N \]

Comparison of Test performance

<table>
<thead>
<tr>
<th>Test Method</th>
<th>Procedure of the randomness test</th>
<th>Accuracy</th>
<th>Normal</th>
<th>Abnormal</th>
<th>All</th>
</tr>
</thead>
<tbody>
<tr>
<td>A</td>
<td>No</td>
<td>Single test</td>
<td>0.50</td>
<td>0.56</td>
<td>0.52</td>
</tr>
<tr>
<td>B</td>
<td>Normal</td>
<td>Proposed denoising</td>
<td>0.84</td>
<td>0.79</td>
<td>0.81</td>
</tr>
<tr>
<td>C</td>
<td>Otsu</td>
<td>Proposed denoising</td>
<td>0.17</td>
<td>0.88</td>
<td>0.51</td>
</tr>
<tr>
<td>D</td>
<td>KDE</td>
<td>No</td>
<td>Step-down</td>
<td>0.78</td>
<td>0.70</td>
</tr>
<tr>
<td>E</td>
<td>KDE</td>
<td>Median Filter</td>
<td>Step-down</td>
<td>0.83</td>
<td>0.75</td>
</tr>
<tr>
<td>F</td>
<td>KDE</td>
<td>Proposed denoising</td>
<td>Bonferroni</td>
<td>0.92</td>
<td>0.71</td>
</tr>
<tr>
<td>G</td>
<td>KDE</td>
<td>Proposed denoising</td>
<td>Step-down</td>
<td>0.91</td>
<td>0.90</td>
</tr>
</tbody>
</table>

• “Step-Down Spatial Randomness Test for Detecting Abnormalities in DRAM Wafers with Multiple Spatial Maps”, IEEE TRANSACTIONS ON SEMICONDUCTOR MANUFACTURING (2016)
• Multi-stage manufacturing process (MSP)
  - A number of stages, which are related to each other via an intricate network of complex relationships
  - A given preceding stage usually affects the final stage through a cascade of both direct and indirect input/output contributions, each of which is hard to model parametrically

• Objective
  - Assess stage variable importance in manufacturing processes characterized by a hierarchy of technical relationships between stages

![Example of MSP](image)

• Variable Importance in a single stage
  - Assess the relative influence that input variables of a given set have on a certain output variable of interest $Y$
  - $Y = f(V_1, ..., V_n; Z_1, ..., Z_m; X_i) + \epsilon$

![Anatomy of a Single Stage](image)

- Regression modeling with random forests
  \[ \max_{j,v} SS_{X_j,v} = \frac{1}{|U|} \sum_{i \in U} (y_i - \bar{y}_v)^2 - \left[ \frac{1}{|S_1|} \sum_{i \in S_1} (y_i - \bar{y}_{S_1,v})^2 + \frac{1}{|S_2|} \sum_{i \in S_2} (y_i - \bar{y}_{S_2,v})^2 \right] \]

- Permutation importance for random forests in regression
  \[ I_j^{Perm} = \frac{1}{T} \sum_{t=1}^{T} (MSE_{t,j} - MSE_t) \]
  where
  \[ MSE_t = \frac{1}{|O_t|} \sum_{i \in O_t} (y_i - \hat{y}_{i,t})^2 \]
  \[ MSE_{t,j} = \frac{1}{|O_t|} \sum_{i \in O_t} (y_i - \hat{y}_{i,t,j})^2 \]

• Stage importance within a multi-stage process
  1) Local relative contribution assessment
  2) Global relative contribution assessment via integration of local relative contribution assessments
  3) Overall procedure for the assessment of stage importance

![Contribution Coefficients in a Given Network](image)

• “Integrated Variable Importance Assessment in Multi-Stage Production Processes”
  (Under revision)