Problem Submission for PIMS 6th Industrial Problem Solving Workshop

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Reverse engineering of integrated circuits is pursued for reasons of competitive analysis or for protection of a manufacturer's intellectual property.

Modern ICs are constructed of an active transistor layer built in the silicon substrate and multiple discrete metal layers, built above the silicon level and separated by an insulating dielectric which signal interconnection and power. ICs are reverse engineered by imaging each layer of the integrated circuit at high magnification and then analyzing the images to reconstruct the original schematics.

An IC is typically too large to fit within the field of view of a microscope. The IC must be imaged in step and repeat manner using a stepping stage. Normally the microscope captures rectangular image tiles of dimension Lx and Ly. The stage is stepped in horizontal and vertical increments of Sx and Sy in a raster pattern to create an image array M rows long and N columns wide. Normally the stepping increments are selected such that Lx > Sx and Ly > Sy so that some overlap always exists between images.

A significant problem is how to create the composite image of the IC from the image tiles.

An image tile in row "i" and column "j" has a reported stage position $X_{i,j}$, $Y_{i,j}$. The reported stage position, however, contains error large enough that the full image of the IC cannot be assembled based on the stage position without creating errors in the final image. These errors might take the form of breaks in a metal line or shorts between adjacent metal lines at the boundaries between the images. An IC is typically characterized by a minimum feature size "F". Positioning accuracy must be greater than F/2 to prevent breaks and shorts.

In addition, the composite images of individual layer must be registered together such that all features are aligned vertically.

An alternative to stage position is to use image analysis of the common overlap regions between adjacent image pairs. Correlation analysis allows offsets to be calculated between any two set of adjacent image pairs. For a pair of images in the same row the offsets in position are Δx_R and Δy_R. For a pair of images in a column the offsets are Δx_C and Δx_R.

The composite image can be re-assembled using these calculated values by butting images together and correcting for the offsets. For instance the X and Y positions of tile with index i,j could be calculated based on the position of its adjacent column neighbor such that:

$$X_{i,j} = X_{i-1,j} + Lx + \Delta x_C, \quad Y_{i,j} = Y_{i-1,j} + Ly + \Delta y_C$$

They might also be calculated based on the position of the adjacent row neighbor

$$X_{i,j} = X_{i,j-1} + Lx + \Delta x_R \qquad Y_{i,j} = Y_{i,j-1} + Ly + \Delta y_R$$

The reassembly may begin at any point in the grid and proceed in any direction. For instance, tiles might be assembled in rows starting from the left hand side of the grid or in columns starting from the top of the grid.

Our question is, what is the most effective method to reassemble the image such that the total error in the image is minimized? Important considerations are:

- the calculated offset values from the correlation analysis contain random error (assume a normal distribution)
- the problem of placing a particular image is over constrained since any image has two possible values of correction to its x position, Δx_R and Δx_C and two possible values of its y position correction, Δy_R and Δy_C.
- since image are assembled in an additive manner, errors will propagate from the starting location