

Chladni and Fractal Dynamics: Dual Mode Marker to Map Cancer Cell Nucleus Disintegration Phases

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Online text S1. Vibroelastic studies of nuclear chromosomes and chromatin

Research on chromosome elasticity reveals that mitotic chromosomes respond elastically to nanonewton-range forces, which is crucial for mechanical regulation during cell division [41]. Chromosomes can be stretched up to 10 times their normal length while maintaining their shape, with breaking occurring at 100 times elongation under ~ 100 nanonewton force [42]. They exhibit a copolymer structure with alternating rigid and semi-flexible regions, and an inner viscoelastic core surrounded by an elastic envelope [43]. As mitosis progresses, chromosomes become more flexible, with the elastic Young modulus decreasing from 5,000 to 1,000 Pa [43]. These findings support a helix-hierarchy model of chromosome structure. Similar elastic properties are observed in nuclei, where macroscopic equations derived from RPA equations of motion describe nuclear vibrations as classical vibrations of an elastic solid [44].

Online text S2. Chladni and fractal simulator: Differences

Fractal Analysis Flow Chart

1. **Start Fractal Analysis**
 - Check if images are loaded.
2. **Load Image as Grayscale**
 - Use OpenCV (cv2.imread(image_path, cv2.IMREAD_GRAYSCALE)).
3. **Isolate Objects**
 - Apply thresholding using Otsu's method.
 - Perform binary opening.
 - Label connected components.
4. **Create Contour**
 - Find contours using the labeled image.
5. **Number Objects**
 - Calculate the center of mass for each labeled region.
6. **Calculate Fractal Dimension**
 - Perform box counting method.
7. **Calculate Lacunarity**
 - Compute lacunarity for different box sizes.
8. **Save and Display Results**
 - Plot the original and processed images.
 - Generate and display the analysis report.
9. **End of Fractal Analysis**

Chladni Pattern Analysis Flow Chart

1. **Start Chladni Pattern Analysis**
 - Check if images are loaded.
2. **Load and Preprocess Image**
 - Convert to grayscale.
 - Apply Gaussian blur.
 - Use adaptive thresholding.
3. **Detect Edges**
 - Apply Canny edge detection.
4. **Find Contours**
 - Extract contours using edge-detected image.
5. **Calculate Basic Features**
 - Calculate pattern density, complexity, area, and symmetry.
6. **Create and Enhance Feature Maps**
 - Density distribution.
 - Loop lengths distribution.
 - Area ratio distribution.
 - Complexity distribution.
 - Circularity distribution.
 - Symmetry score distribution.
7. **Save and Display Results**

- Plot the feature maps.
 - Generate and display the analysis report.
- 8. End of Chladni Pattern Analysis**

Differences in Flow Charts

- **Complexity of Image Processing:**
 - The fractal analysis involves simpler image processing with a focus on labeling and analyzing the geometry and scaling properties of structures within the image as the structure grows as a function of time. So, we get a spatial scale variation.
 - Chladni pattern analysis is more complex, involving edge detection, feature extraction, and detailed mapping of various properties like density, area, and symmetry across the image, but we can get complete picture in one image.
- **Mathematical Operations:**
 - Fractal analysis computes the fractal dimension and lacunarity, which are mathematical measures of pattern complexity and texture irregularity, respectively.
 - Chladni pattern analysis calculates more physical features such as density, complexity, and symmetry, which require spatial distribution and morphological evaluations.
- **Objective:**
 - Fractal analysis aims to quantify self-similarity and pattern roughness.
 - Chladni pattern analysis seeks to map and visualize different physical properties of patterns, giving a more spatial and visual interpretation of data.

These distinctions can be visually represented in flow charts, where the fractal analysis would focus on numerical analysis and calculations, while the Chladni analysis would be more oriented towards image processing and feature mapping.

Figure S1. Experimental images showing nuclear transition

For analyzing fractal dynamics and Chladni pattern, we have divided a 50 minutes experiment into 22 parts and these 22 images showing different phases of nuclear transition as given below:

