Target: Cell Simulation based on Mechanics

- Cell structure/morphology as a system
- Membrane (2D): Organelles (vesicles, Golgi, ...)
- Cytoskeleton (1D & 2D): Lamellipodia, Filopodia, ...
- Adhesion (3D): Cell-to-cell, To substrate, ...
- Biochemically:
  - Elements: Proteins, biomolecules, ...
  - Structure to functional system through hierarchy
- Mechanically:
  - System dynamics based on mass and energy principles
  - Discrete interactions to continuum behavior in 3D field

Cellular Function from Interaction between Biochemical and Mechanical Factors

Approaches

- Interactions between biomech. & biochem. interactions essential for dynamical functions of cell mechanical system
- From local molecular functions at discrete molecular levels to cellular functions at continuum field levels
- System tools to study temporal and spatial structure-function relationships at both discrete and continuum levels.

Mechanics of Structural System

- Elastic deformation of membrane, fiber under constraint
- Conservation / non-cons. of mass & energy
- Cytoskeleton reorganization
- Filament polymerization / depolymerization
- Membrane, endocytosis, ...
- Cell migration, mitosis, ...

Study on relationship between strain and depolymerization of actin structure in the crawling mechanism

Method: Visualization & Imaging

Injection Qdot-phalloidin
Injection pressure: P = 60~70 kPa
Injection time: t = 0.2~0.4 sec

Observed by CCD camera
Frame rate = 4 sec/frame
Exposure time: t_e = 600 msec

Injection Qdot-phalloidin
Injection pressure: P = 60~70 kPa
Injection time: t = 0.2~0.4 sec

Injection Qdot-phalloidin
Injection pressure: P = 60~70 kPa
Injection time: t = 0.2~0.4 sec

Actin Dynamics in Cell Locomotion

30 μm

Cytoskeletal actin fiber networks in a crawling fish keratocyte

Promotion of the leading edge through assembly and disassembly; Pollard, T. D., Nature, 2003

Intracellular stress

Crawling direction

Cell body Trunk of speckle Leading edge

Displacement field

Courtesy of Y. Shitagawa (Kyoto University)

Negative incremental strain
Actin filament depolymerization
Orientation of actin structure gradually becomes perpendicular to the crawling direction

Actin filament depolymerized

Result

\[ \Delta \epsilon : \text{Compressive incremental strain} \]

Change in filament angle

Bounded angle of actin filament becomes perpendicular to crawling direction.

Discussion

Positive incremental strain
Actin filament depolymerization
Orientation of actin structure gradually becomes perpendicular to the crawling direction

Actin filaments parallel to the crawling direction depolymerized gradually depending on the fiber strain.

Stress fiber depolymerized by compressive strain (Release of tension)


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