**Topic:**

**Cell Migration**

# What is cell migration:

Cell migration is the directed movement of a single cell or a group of cells in response to chemical and/or [mechanical signals](https://www.mechanobio.info/what-is-mechanosignaling/). It is a fundamental cellular process that occurs throughout life, starting during [embryonic development](https://www.mechanobio.info/development/) and continuing until death, and at times it can contribute to [pathogenic states](https://www.mechanobio.info/pathogenesis/) in disease.

In a developing embryo, cell migration is the driving factor for various morphogenetic events. For instance, during gastrulation in very early embryos, groups of cells migrate as sheets to form the three germ layers. Subsequently, cells from the germ layers migrate to various target locations, where they specialize into distinct cell populations that make up various tissues or organs in the embryo.

In adult organisms, cell migration occurs during vital cellular processes such as tissue renewal and repair, wherein old or damaged cells are replaced by the migration of newly formed cells from the underlying tissue layers. Such events are essential to maintain tissue integrity and homeostasis. Cell migration also plays a role in mediating immune responses during infections, in which phagocytic cells such as neutrophils circulating in the bloodstream migrate to the infected tissues and destroy the invading pathogens.

While on one hand, cell migration is vital for maintaining tissue health and homeostasis, on the other hand, undesirable migratory events are causative factors for a number of pathological states such as inflammatory diseases, cancers, and so on. Therefore, migration of cells has to be a tightly controlled process -both in time and space- to maintain a homeostatic state in an organism.

## ****Cell migration as a cyclic process:****

The migration of a single cell or a group of cells is regarded as a cyclic process, which involves the [polarization of cells](https://www.mechanobio.info/faq-items/what-is-cell-polarity-2/) in response to migratory signals, the extension of filo podial or lamelli podial protrusions, the formation of adhesions between the cell and the underlying matrix, and the pushing of the cells over the adhesions as a result of traction forces generated by the adhesions.

**Polarization of migrating cells:**

The first step in directional migration is the polarization of cells, during which the front and the back of the cell become different in structure and molecular composition. The [Rho](https://www.mechanobio.info/family/Rho%20GTPases/) family of GTPases, mainly Rac, Cdc42, and Rho, are one of the key regulators of cell polarization, with each of them showing localized activity in cells . While Rac and Cdc42 show localized activity at the leading edge, active Rho accumulates at the sides and rear of the cell.  Cdc42 also regulates the MTOC to localize in front of the nucleus, closer to the leading edge. This is mediated through Cdc42 effector PAR6, which forms the “PAR polarity complex along with PAR3 and PKC binds to [tubulin](https://www.mechanobio.info/family/tubulin/) subunits on the newly forming microtubules and anchors them at the leading edge. The assembly of the microtubules towards the leading edge facilitates the delivery of cargo (membrane and proteins) that are used in the formation of cell protrusions .

**Extension of protrusions:**

A polarized cell starts putting forth actin-based protrusions at its leading edge, such as lamellipodia or filopodia. Lamellipodia are formed as branched, dendritic networks of actin filaments, and therefore are able to push along a broader stretch of the membrane. Filopodia, on the other hand, are formed as parallel bundles of actin filaments, and have roles mainly in sensing the physical properties of the extracellular environment. The molecular mechanisms driving the formation of these protrusions are different; lamellipodia are formed by the [Arp2/3](https://www.mechanobio.info/family/Arp2/3%20complex/) complex proteins, which bind to the sides of preexisting filaments and initiate the assembly of newer filaments that branch off from the parent filament. The activity of the Arp2/3 complex is regulated by the [Wasp/Wave](https://www.mechanobio.info/family/Nucleation%20promoting%20factors/) family of proteins, which are in turn regulated by the Rho GTPases. Filopodial assembly occurs through a treadmilling mechanism, in which actin monomers get added to one (barbed) end and disassembled at the other (pointed) end at a steady state. A number of actin-binding proteins like [Ena/Vasp](https://www.mechanobio.info/family/Ena/Vasp/), [fascin](https://www.mechanobio.info/family/Fascin/), [ADF/cofilin](https://www.mechanobio.info/family/ADF/cofilin%20family/), and capping proteins regulate the rate of filopodial actin assembly.

**Formation of Adhesions:**

The extension of protrusions is accompanied by the assembly of molecular structures called [focal adhesions](https://www.mechanobio.info/faq-items/what-are-focal-adhesions-and-how-do-they-function-as-mechanosensors/) that connect the actin cytoskeleton to the extracellular matrix (ECM). This is often initiated by interactions between components of the ECM (ligands) and receptors (primarily [integrins](https://www.mechanobio.info/family/Integrin/)) on cell surfaces, which then switches on distinct intracellular signaling pathways and causes the sequential recruitment of several scaffolding, signaling, and regulatory proteins to sites of focal adhesions.

Focal adhesions serve two important functions at the leading edge: as traction sites against which cells generate tensional forces to push themselves forward, and as mechanosensors that convey information about the physical properties of the matrix to the cell interior. Tensional forces are generated due to the interaction of [myosin](https://www.mechanobio.info/family/Myosins/) bundles with actin filaments anchored at focal adhesion sites, and the contractile activity between the two molecular assemblies.

The migratory capabilities of cells rely on the strength of focal adhesions, which is influenced by factors like ligand density, receptor density, and the affinity between the ligand and the receptor. For instance, rapidly migrating cells have very few integrin clusters and therefore these cells form very few, submicroscopic adhesions. Cells with evenly distributed integrin clusters form smaller adhesions called focal complexes that stabilize the protrusions, but can also dissociate easily, leading to efficient migration. On the other hand, cells with mature focal adhesions are highly adherent and therefore are non-migratory or move slowly.

Disassembly of adhesions: Adhesion disassembly occurs both at the leading edge and the rear of a migrating cells. At the leading edge, older adhesions at the base of the protrusion usually disassemble; however, some of them do not and instead grow into more mature molecular assemblies. The disassembly of adhesions at the front is regulated by kinases like =[FAK](https://www.mechanobio.info/family/Focal%20adhesion%20kinase/) and [Src](https://www.mechanobio.info/family/Src%20family%20kinase/), as well as by phosphatases. Several studies in this area have led to a model for Src/FAK-mediated signaling pathway, in which active forms of these kinases lead to the activation of Rac and [Erk](https://www.mechanobio.info/family/ERK/). The final response is the turnover of adhesions in response to activation signals. Adhesion turnover at the rear is essential for tail retraction and the forward protrusion of cells and is mainly regulated by myosin II-dependent actin filamentcontractility . Additionally, intracellular calcium levels are known to play a key role in regulating this subcellular event.

# How and Why Cells Move:

[**Cell**](https://www.thoughtco.com/types-of-cells-in-the-body-373388)**movement** is a necessary function in organisms. Without the ability to move, cells could not grow and divide or migrate to areas where they are needed. The [cytoskeleton](https://www.thoughtco.com/cytoskeleton-anatomy-373358) is the component of the cell that makes cell movement possible. This network of fibers is spread throughout the cell's [cytoplasm](https://www.thoughtco.com/cytoplasm-defined-373301) and holds [organelles](https://www.thoughtco.com/organelles-meaning-373368) in their proper place. Cytoskeleton fibers also move cells from one location to another in a fashion that resembles crawling.

**Why Do Cells Move?**

[Cell](https://www.thoughtco.com/facts-about-cells-373372) movement is required for a number of activities to occur within the body. [White blood cells](https://www.thoughtco.com/types-of-white-blood-cells-373374), such as neutrophils and [macrophages](https://www.thoughtco.com/macrophages-meaning-373352) must quickly migrate to sites of infection or injury to fight bacteria and other germs. Cell motility is a fundamental aspect of form generation **(morphogenesis)** in the construction of tissues, organ sand the determination of cell shape. In cases involving wound injury and repair, [connective tissue](https://www.thoughtco.com/connective-tissue-anatomy-373207) cells must travel to an injury site to repair damaged tissue. [Cancer cells](https://www.thoughtco.com/facts-about-cancer-cells-373373) also have the ability to metastasize or spread from one location to another by moving through [blood vessels](https://www.thoughtco.com/blood-vessels-373483) and [lymphatic vessels](https://www.thoughtco.com/lymphatic-vessels-anatomy-373245). In the [cell cycle](https://www.thoughtco.com/understanding-the-cell-cycle-373391), movement is required for the cell dividing process of cytokinesis to occur in the formation of two [daughter cells](https://www.thoughtco.com/daughter-cells-defined-4024745). Steps of Cell Movement

**Cell motility** is accomplished through the activity of**cytoskeleton fibers**. These fibers include [microtubules](https://www.thoughtco.com/microtubules-373545), microfilaments or actin filaments and intermediate filaments. Microtubules are hollow rod-shaped fibers that help support and shape cells. Actin filaments are solid rods that are essential for movement and muscle contraction. Intermediate filaments help stabilize **microtubules and microfilaments** by keeping them in place. During cell movement, the cytoskeleton disassembles and re-assembles actin filaments and microtubules. The energy required to produce movement comes from adenosine triphosphate (ATP). ATP is a high energy molecule produced in [cellular respiration](https://www.thoughtco.com/cellular-respiration-process-373396).

## Steps of Cell Movement:

Cell adhesion molecules on cell surfaces hold cells in place to prevent undirected migration. Adhesion molecules hold cells to other cells, cells to the **extracellular matrix (ECM)** and the ECM to the cytoskeleton. The extracellular matrix is a network of [proteins](https://www.thoughtco.com/proteins-373564), [carbohydrates](https://www.thoughtco.com/carbohydrates-373558) and fluids that surround cells. The ECM helps to position cells in tissues, transport communication signals between cells and reposition cells during cell migration. Cell movement is prompted by chemical or physical signals that are detected by proteins found on [cell membranes](https://www.thoughtco.com/cell-membrane-373364). Once these signals are detected and received, the cell begins to move. There are three phases to cell movement.

* **In the first phase**, the cell detaches from the extracellular matrix at its foremost position and extends forward.
* **In the second phase**, the detached portion of the cell moves forward and re-attaches at a new forward position. The rear portion of the cell also detaches from the extracellular matrix.
* **In the third phase**, the cell is pulled forward to a new position by the motor protein myosin. Myosin utilizes the energy derived from ATP to move along actin filaments, causing cytoskeleton fibers to slide along one another. This action causes the entire cell to move forward.

The cell moves in the direction of the detected signal. If the cell is responding to a chemical signal, it will move in the direction of the highest concentration of signal molecules. This type of movement is known **as chemotaxis**.

## Movement Within Cells:

Not all cell movement involves the repositioning of a cell from one place to another. Movement also occurs within cells. Vesicle transportation, [organelle](https://www.thoughtco.com/organelles-meaning-373368) migration, and [chromosome](https://www.thoughtco.com/chromosome-373462) movement during [mitosis](https://www.thoughtco.com/stages-of-mitosis-373534) are examples of types of internal cell movement.

**Vesicle transportation** involves the movement of molecules and other substances into and out of a cell. These substances are enclosed within vesicles for transportation. Endocytosis, [pinocytosis](https://www.thoughtco.com/pinocytosis-definition-4143229), and [exocytosis](https://www.thoughtco.com/what-is-exocytosis-4114427) are examples of vesicle transportation processes. In **phagocytosis,** a type of endocytosis, foreign substances and unwanted material are engulfed and destroyed by white blood cells. The targeted matter, such as a [bacterium](https://www.thoughtco.com/bacteria-that-live-on-your-skin-373528), is internalized, enclosed within a vesicle, and degraded by enzymes.

**Organelle migration and chromosome movement** occur during cell division. This movement ensures that each replicated cell receives the appropriate complement of chromosomes and organelles. Intracellular movement is made possible by motor [proteins](https://www.thoughtco.com/protein-function-373550), which travel along cytoskeleton fibers. As the motor proteins move along microtubules, they carry organelles and vesicles with them.

## Cilia and Flagella:

Some cells possess cellular appendage-like protrusions called [cilia and flagella](https://www.thoughtco.com/cilia-and-flagella-373359). These cell structures are formed from specialized groupings of microtubules that slide against one another allowing them to move and bend. Compared to flagella, cilia are much shorter and more numerous. Cilia move in a wave-like motion. Flagella are longer and have more of a whip-like movement. Cilia and flagella are found in both [plant cells](https://www.thoughtco.com/what-is-a-plant-cell-373384) and [animal cells](https://www.thoughtco.com/all-about-animal-cells-373379).

[Sperm cells](https://www.thoughtco.com/sex-cells-meaning-373386) are examples of body cells with a single flagellum. The flagellum propels the sperm cell toward the female oocyte for [fertilization](https://www.thoughtco.com/sexual-reproduction-types-of-fertilization-373440). Cilia are found within areas of the body such as the [lungs](https://www.thoughtco.com/anatomy-of-the-lungs-373249) and [respiratory system](https://www.thoughtco.com/respiratory-system-4064891), parts of the [digestive tract](https://www.thoughtco.com/digestive-system-373572), as well as in the [female reproductive tract](https://www.thoughtco.com/reproductive-system-373583). Cilia extend from the epithelium lining the lumen of these body system tracts. These hair-like threads move in a sweeping motion to direct the flow of cells or debris. For example, cilia in the respiratory tract help to propel mucus, [pollen](https://www.thoughtco.com/facts-about-pollen-373610), dust, and other substances away from the lungs.

# Cell Migration:

Cell migration is fundamental to establishing and maintaining the proper organization of multicellular organisms. Morphogenesis can be viewed as a consequence, in part, of cell locomotion, from large-scale migrations of epithelial sheets during gastrulation, to the movement of individual cells during development of the nervous system. In an adult organism, cell migration is essential for proper immune response, wound repair, and tissue homeostasis, while aberrant cell migration is found in various pathologies. Indeed, as our knowledge of migration increases, we can look forward to, for example, abating the spread of highly malignant cancer cells, retarding the invasion of white cells in the inflammatory process, or enhancing the healing of wounds. This article is organized in two main sections. The first section is devoted to the single cell migrating in isolation such as occurs when leukocytes migrate during the immune response or when fibroblasts squeeze through connective tissue. The second section is devoted to cells collectively migrating as part of multicellular clusters or sheets. This second type of migration is prevalent in development, wound healing, and in some forms of cancer metastasis.

Cell migration is a central process in the development and maintenance of [multicellular organisms](https://en.wikipedia.org/wiki/Multicellular_organism). Tissue formation during [embryonic development](https://en.wikipedia.org/wiki/Embryogenesis), [wound healing](https://en.wikipedia.org/wiki/Wound_healing) and [immune responses](https://en.wikipedia.org/wiki/Immune_system) all require the orchestrated movement of cells in particular directions to specific locations. Cells often migrate in response to specific external signals, including [chemical signals](https://en.wikipedia.org/wiki/Chemotaxis) and [mechanical signals](https://en.wikipedia.org/wiki/Mechanotaxis). Errors during this process have serious consequences, including [intellectual disability](https://en.wikipedia.org/wiki/Intellectual_disability), [vascular disease](https://en.wikipedia.org/wiki/Cardiovascular_disease), [tumor formation](https://en.wikipedia.org/wiki/Tumor) and [metastasis](https://en.wikipedia.org/wiki/Metastasis). An understanding of the mechanism by which cells migrate may lead to the development of novel therapeutic strategies for controlling, for example, invasive tumors cells.

Due to the highly viscous environment (low [Reynolds number](https://en.wikipedia.org/wiki/Reynolds_number)), cells need to continuously produce forces in order to move. Cells achieve active movement by very different mechanisms. Many less complex prokaryotic organisms (and sperm cells) use [flagella](https://en.wikipedia.org/wiki/Flagella) or [cilia](https://en.wikipedia.org/wiki/Cilia) to propel themselves. [Eukaryotic](https://en.wikipedia.org/wiki/Eukaryotic) cell migration typically is far more complex and can consist of combinations of different migration mechanisms. It generally involves drastic changes in cell shape which are driven by the [cytoskeleton](https://en.wikipedia.org/wiki/Cytoskeleton). Two very distinct migration scenarios are crawling motion (most commonly studied) and blebbing motility. A paradigmatic example of crawling motion is the case of fish epidermal keratocytes, which have been extensively used in research and teaching.

**Cell migration Studies:**

The migration of [cultured cells](https://en.wikipedia.org/wiki/Cell_culture) attached to a surface is commonly studied using [microscopy](https://en.wikipedia.org/wiki/Microscopy). As cell movement is very slow, a few µm/minute, [time-lapse microscopy](https://en.wikipedia.org/wiki/Time-lapse_microscopy) videos are recorded of the migrating cells to speed up the movement. Such videos reveal that the leading cell front is very active, with a characteristic behavior of successive contractions and expansions. It is generally accepted that the leading front is the main motor that pulls the cell forward.

### Common features:

The processes underlying mammalian cell migration are believed to be consistent with those of (non-[spermatozoic](https://en.wikipedia.org/wiki/Spermatozoon)) [locomotion](https://en.wikipedia.org/wiki/Amoeboid_movement). Observations in common include:

* cytoplasmic displacement at leading edge (front)
* laminar removal of dorsally accumulated debris toward trailing edge (back)

The latter feature is most easily observed when aggregates of a surface molecule are cross-linked with a fluorescent [antibody](https://en.wikipedia.org/wiki/Antibody) or when small beads become artificially bound to the front of the cell.

Other eukaryotic cells are observed to migrate similarly. The amoeba [Dictyostelium discoideum](https://en.wikipedia.org/wiki/Dictyostelium_discoideum) is useful to researchers because they consistently exhibit chemotaxis in response to [cyclic AMP](https://en.wikipedia.org/wiki/Cyclic_adenosine_monophosphate); they move more quickly than cultured mammalian cells; and they have a [haploid](https://en.wikipedia.org/wiki/Haploid) genome that simplifies the process of connecting a particular gene product with its effect on cellular behavior.

**Molecular Processes of Migration:**

There are two main theories for how the cell advances its front edge: the cytoskeletal model and membrane flow model. It is possible that both underlying processes contribute to cell extension.

### Cytoskeletal model (A):

### Leading edge:

Experimentation has shown that there is rapid [actin](https://en.wikipedia.org/wiki/Actin) polymerization at the cell's front edge.[]](https://en.wikipedia.org/wiki/Cell_migration#cite_note-Wang1985-8) This observation has led to the hypothesis that formation of actin filaments "push" the leading edge forward and is the main motile force for advancing the cell's front edge. In addition, cytoskeletal elements are able to interact extensively and intimately with a cell's plasma membrane.

### Trailing edge:

Other cytoskeletal components (like microtubules) have important functions in cell migration. It has been found that microtubules act as “struts” that counteract the contractile forces that are needed for trailing edge retraction during cell movement. When microtubules in the trailing edge of cell are dynamic, they are able to remodel to allow retraction. When dynamics are suppressed, microtubules cannot remodel and, therefore, oppose the contractile forces. The morphology of cells with suppressed microtubule dynamics indicate that cells can extend the front edge (polarized in the direction of movement), but have difficulty retracting their trailing edge. On the other hand, high drug concentrations, or microtubule mutations that depolymerize the microtubules, can restore cell migration but there is a loss of directionality. It can be concluded that microtubules act both to restrain cell movement and to establish directionality.

### Membrane flow model (B):

Studies have also shown that the front of the migration is the site at which the membrane is returned to the cell surface from internal membrane pools at the end of the [endocytic cycle](https://en.wikipedia.org/wiki/Endocytic_cycle). This has led to the hypothesis that extension of the leading edge occurs primarily by addition of membrane at the front of the cell. If so, the actin filaments that form at the front might stabilize the added membrane so that a structured extension, or lamella, is formed rather than a bubble-like structure (or bleb) at its front.[[15]](https://en.wikipedia.org/wiki/Cell_migration#cite_note-Bretscher1996-15) For a cell to move, it is necessary to bring a fresh supply of "feet" (proteins called [integrins](https://en.wikipedia.org/wiki/Integrins), which attach a cell to the surface on which it is crawling) to the front. It is likely that these feet are endocytosed toward the rear of the cell and brought to the cell's front by exocytosis, to be reused to form new attachments to the substrate.

### Mechanistic basis of amoeboid migration:

Adhesive crawling is not the only migration mode exhibited by eukaryotic cells. Importantly, metastatic cancer cells and immune cells like [macrophages](https://en.wikipedia.org/wiki/Macrophage) and [neutrophils](https://en.wikipedia.org/wiki/Neutrophil) have been found to be capable of adhesion-independent migration. The mechanistic basis of this migration mode is less understood than either eukaryotic cell crawling or flagella-based swimming by microorganisms. The physicist [E. M. Purcell](https://en.wikipedia.org/wiki/Edward_Mills_Purcell)theorized that under conditions of low [Reynolds number](https://en.wikipedia.org/wiki/Reynolds_number) fluid dynamics, which apply at the cellular scale, rearward surface flow could provide a mechanism for microscopic objects to swim forward. After some decades, experimental support for this model was provided using [optogenetics](https://en.wikipedia.org/wiki/Optogenetics). It was shown that cells migrating in an amoeboid fashion without adhesions exhibit plasma membrane flow towards the cell rear that can propel cells by exerting tangential forces on the surrounding fluid. Polarized trafficking of membrane-containing vesicles from the rear to the front of the cell helps maintain cell size.[[16]](https://en.wikipedia.org/wiki/Cell_migration#cite_note-O'Neill-16) Rearward membrane flow was also observed in Dictyostelium discoideumcells. Interestingly, the migration of supra cellular clusters has also been found to be supported by a similar mechanism of rearward surface flow.

### Collective biomechanical and molecular mechanism of cell motion:

Based on some mathematical models, recent studies hypothesize a novel biological model for collective biomechanical and molecular mechanism of cell motion. It is proposed that microdomains weave the texture of cytoskeleton and their interactions mark the location for formation of new adhesion sites. According to this model, microdomain signaling dynamics organizes cytoskeleton and its interaction with substratum. As microdomains trigger and maintain active polymerization of actin filaments, their propagation and zigzagging motion on the membrane generate a highly interlinked network of curved or linear filaments oriented at a wide spectrum of angles to the cell boundary. It is also proposed that microdomain interaction marks the formation of new focal adhesion sites at the cell periphery. Myosin interaction with the action network then generate membrane retraction/ruffling, retrograde flow, and contractile forces for forward motion. Finally, continuous application of stress on the old focal adhesion sites could result in the calcium-induced calpain activation, and consequently the detachment of focal adhesions which completes the cycle.

**Polarity in Migration Cells:**

Migrating cells have a [polarity](https://en.wikipedia.org/wiki/Cell_polarity)—a front and a back. Without it, they would move in all directions at once, i.e. spread. How this polarity is formulated at a molecular level inside a cell is unknown. In a cell that is meandering in a random way, the front can easily give way to become passive as some other region, or regions, of the cell form(s) a new front. In chemo taxing cells, the stability of the front appears enhanced as the cell advances toward a higher concentration of the stimulating chemical. This polarity is reflected at a molecular level by a restriction of certain molecules to particular regions of the inner [cell surface](https://en.wikipedia.org/wiki/Cell_membrane). Thus, the phospholipid [PIP3](https://en.wikipedia.org/wiki/Phosphatidylinositol_(3,4,5)-trisphosphate)and activated Rac and [CDC42](https://en.wikipedia.org/wiki/CDC42) are found at the front of the cell, whereas [Rho GTPase](https://en.wikipedia.org/wiki/RHOA) and [PTEN](https://en.wikipedia.org/wiki/PTEN_(gene)) are found toward the rear.

It is believed that filamentous actins and [microtubules](https://en.wikipedia.org/wiki/Microtubule) are important for establishing and maintaining a cell's polarity. Drugs that destroy actin filaments have multiple and complex effects, reflecting the wide role that these filaments play in many cell processes. It may be that, as part of the locomotory process, membrane [vesicles](https://en.wikipedia.org/wiki/Vesicle_(biology)) are transported along these filaments to the cell's front. In chemo taxing cells, the increased persistence of migration toward the target may result from an increased stability of the arrangement of the filamentous structures inside the cell and determine its polarity. In turn, these filamentous structures may be arranged inside the cell according to how molecules like PIP3 and PTEN are arranged on the inner cell membrane. And where these are located appears in turn to be determined by the chemoattractant signals as these impinge on specific [receptors](https://en.wikipedia.org/wiki/Receptor_(biochemistry)) on the cell's outer surface.

Although microtubules have been known to influence cell migration for many years, the mechanism by which they do so has remained controversial. On a planar surface, microtubules are not needed for the movement, but they are required to provide directionality to cell movement and efficient protrusion of the leading edge. When present, microtubules retard cell movement when their dynamics are suppressed by drug treatment or by tubulin mutations.

**Inverse Problems in the Context of Cell motility:**

An area of research called [inverse problems](https://en.wikipedia.org/wiki/Inverse_problem) in cell motility has been established.  This approach is based on the idea that behavioral or shape changes of a cell bear information about the underlying mechanisms that generate these changes. Reading cell motion, namely, understanding the underlying biophysical and mechanochemical processes, is of paramount importance.  The mathematical models developed in these works determine some physical features and material properties of the cells locally through analysis of live cell image sequences and uses this information to make further inferences about the molecular structures, dynamics, and processes within the cells, such as the action network, microdomains, chemotaxis, adhesion, and retrograde flow.