A Criterion for the Persistence of Cell Movement

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Outline

i)The theory of Brownian motion / random walk.

ii)The *persistent* random walk.

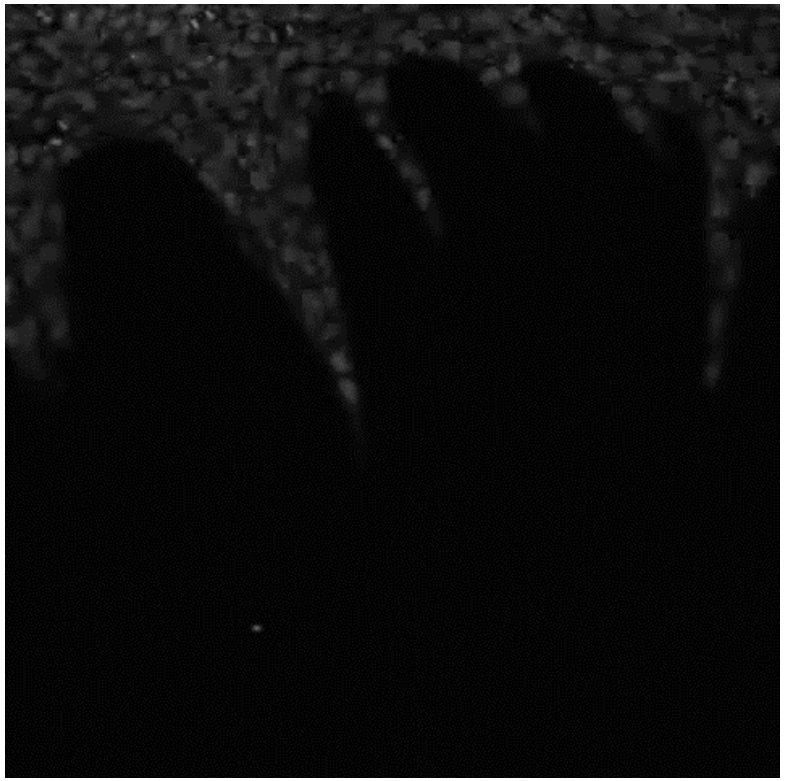
iii)Migration of the MS-1 cell that has an angiogenic property.

iv)a new criterion for the *persistence* of cell movement.

Background: The directional persistence in cell movement, we consider, will be a key to understanding angiogenic morphogenesis from the viewpoint of collective phenomena.

The MS-1 cell: mouse pancreatic islet-derived capillary endothelial cell line

Angiogenic property: sprouting



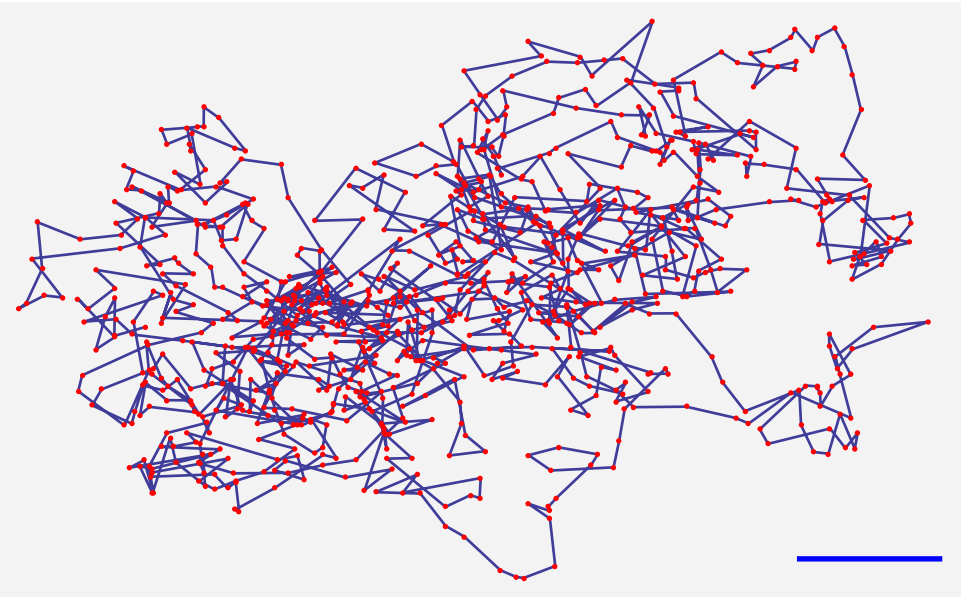
5 min interval / 2 days

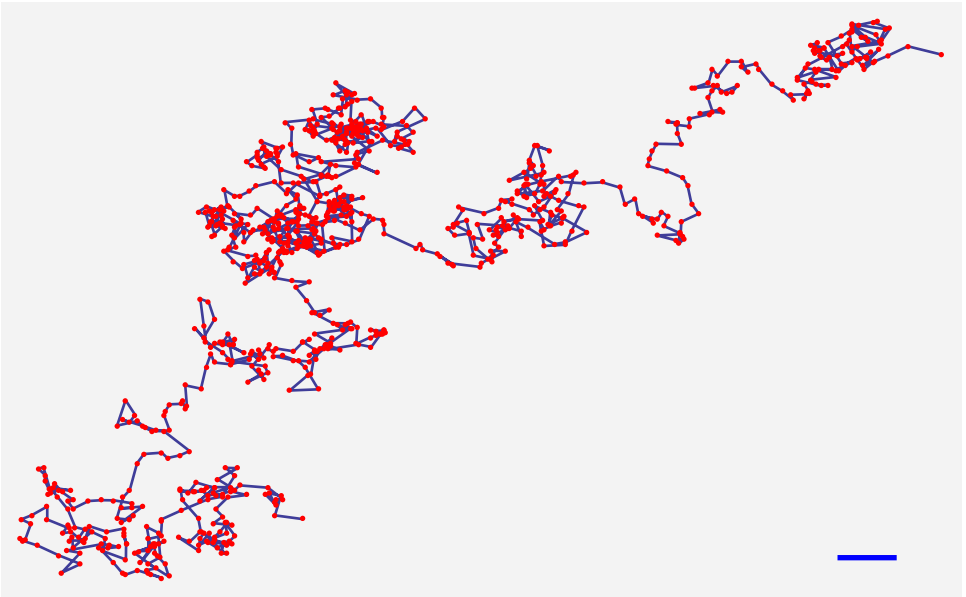
Single-cell migration of the MS-1 cell

5 min interval / 1 day

Brownian Motion / Random Walk

Two samples of random walk generated by the same condition.



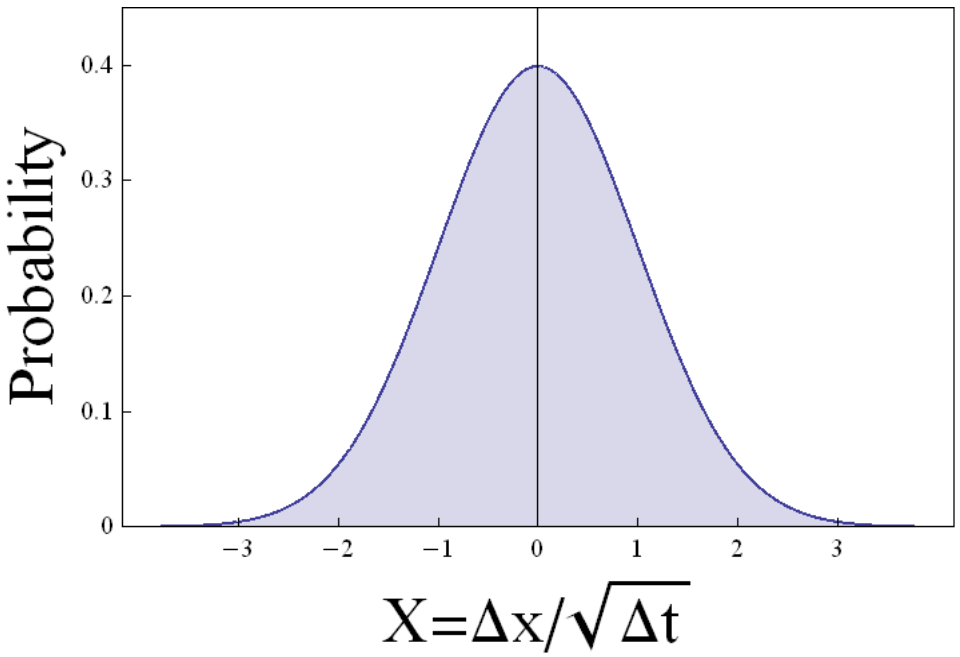


We cannot tell just by looking if it is a Brownian motion or not.

Theory of Brownian Motion

- Fourier's law of heat conduction
$$(\Delta T)^2 \propto \Delta t$$
- Fick's law of concentration diffusion in solution
$$(\Delta C)^2 \propto \Delta t$$
- Einstein's theory of Brownian motion
$$\langle (\Delta x)^2 \rangle \propto \Delta t$$

- Normal distribution with mean 0 and variance Δt



Statistics of Trajectories

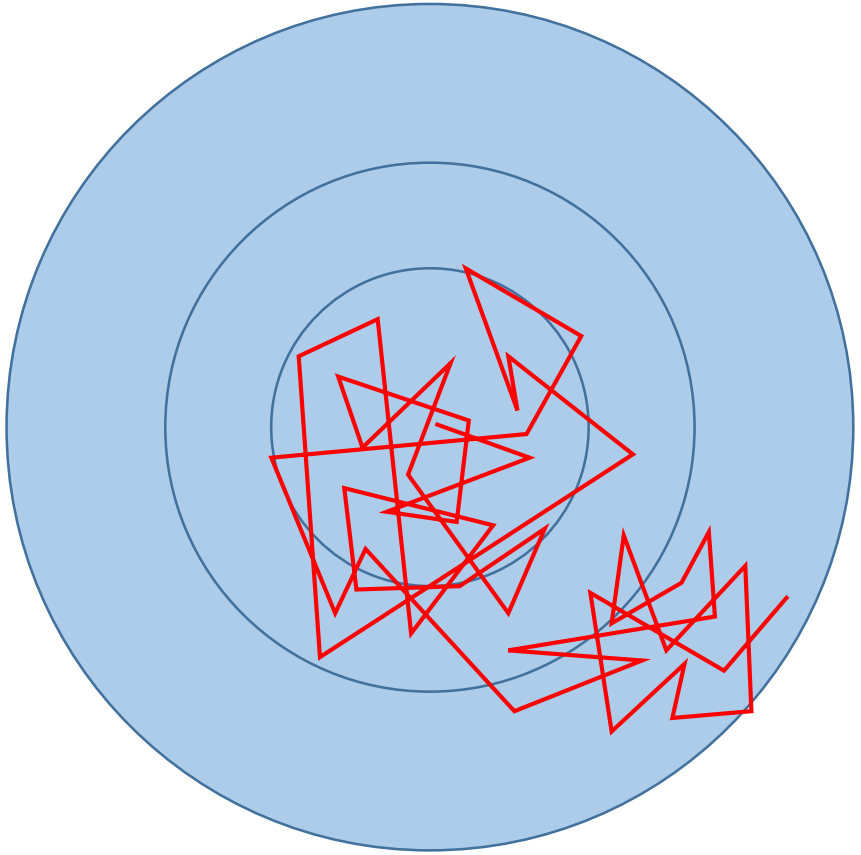
Mean Squared Displacement

Variance of the displacements.

Evaluation of the area explored by cells over time.

Einstein's theory implies

$$MSD(t) \propto t$$



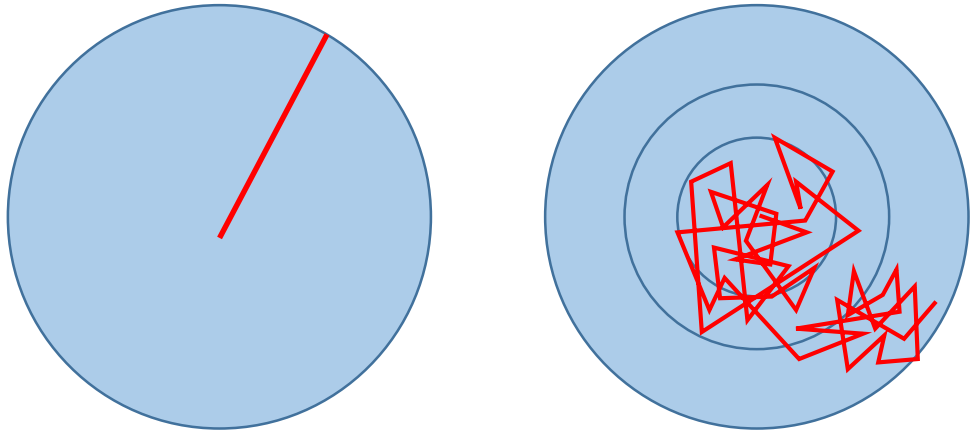
Persistent Random Walk

Persistent random walk

$$MSD(t) \propto \begin{cases} t^2 & (\text{short time } t \ll P) \\ t & (\text{long time } t \gg P) \end{cases}$$

The persistence time *P*

The time the crossover occurs from linear motion to random walk.



Linear motion

Random walk

Criterion for the Persistence of Cell Movement

The Persistence at time *t* of order 3:

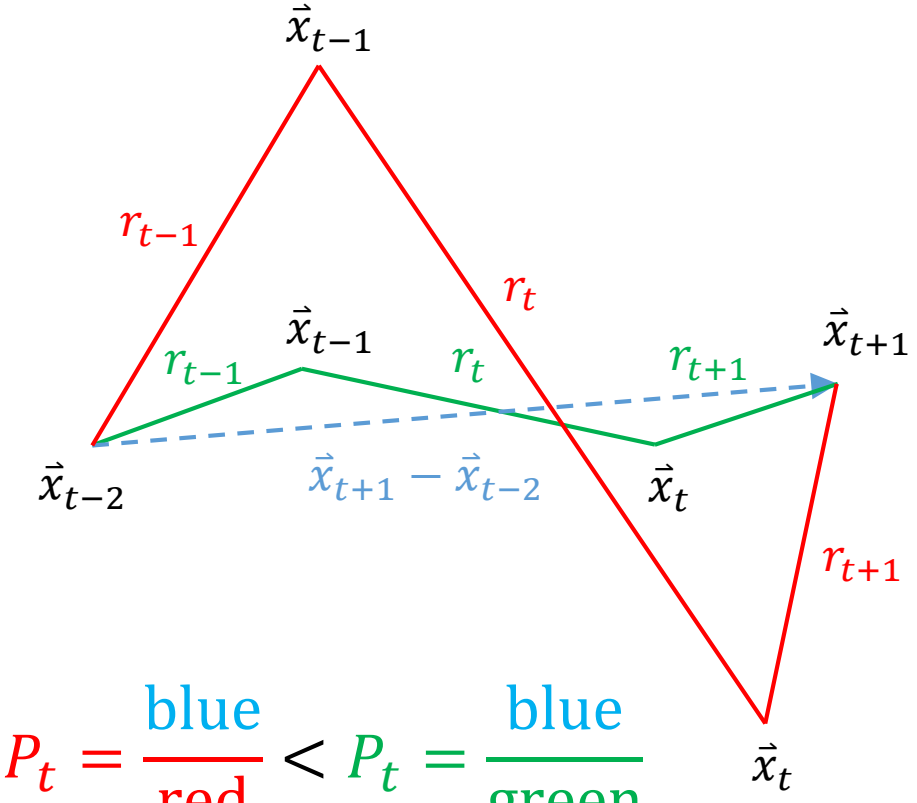
$$P_t = \frac{|\vec{x}_{t+1} - \vec{x}_{t-2}|}{r_{t-1} + r_t + r_{t+1}} \quad (r_t = |\vec{x}_t - \vec{x}_{t-1}|)$$

calculated from 4 consecutive time points.

Persistence of order *n* is calculated from *n+1* points.

cf. Directional Ratio:

$$DR = \frac{\text{distance from the beginning to the end}}{\text{total distance traveled}}$$



$$P_t = \frac{\text{blue}}{\text{red}} < P_t = \frac{\text{blue}}{\text{green}}$$

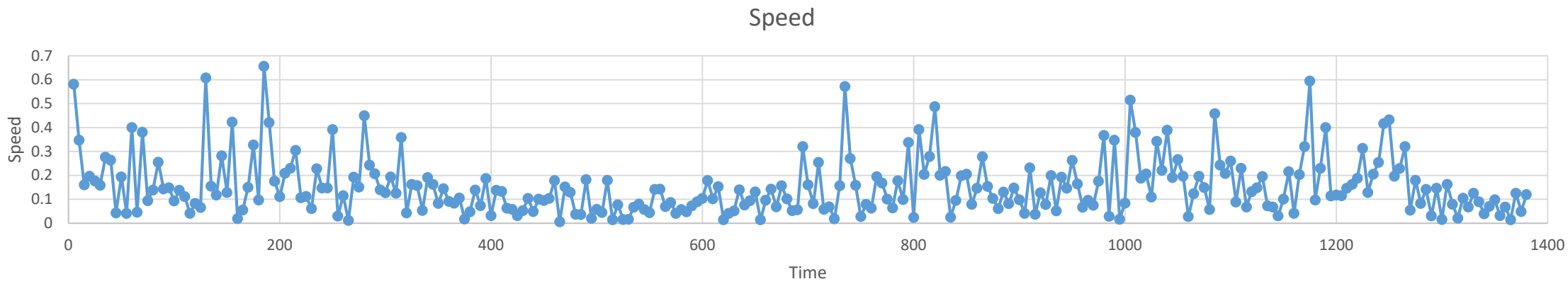
Application to the Trajectory of the MS-1 Cell

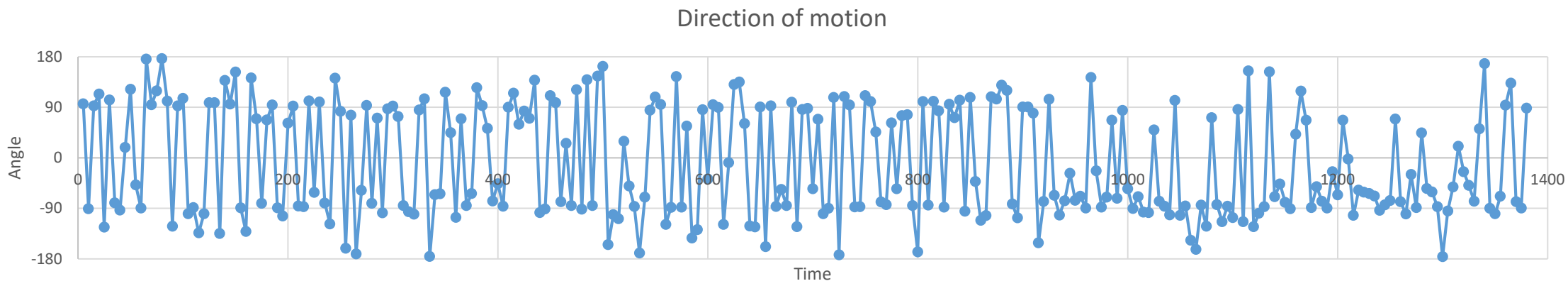
In the early stage, the MS-1 cell seems to only fluctuate.

In the later stage, it seems to make a persistent movement in the downward direction.

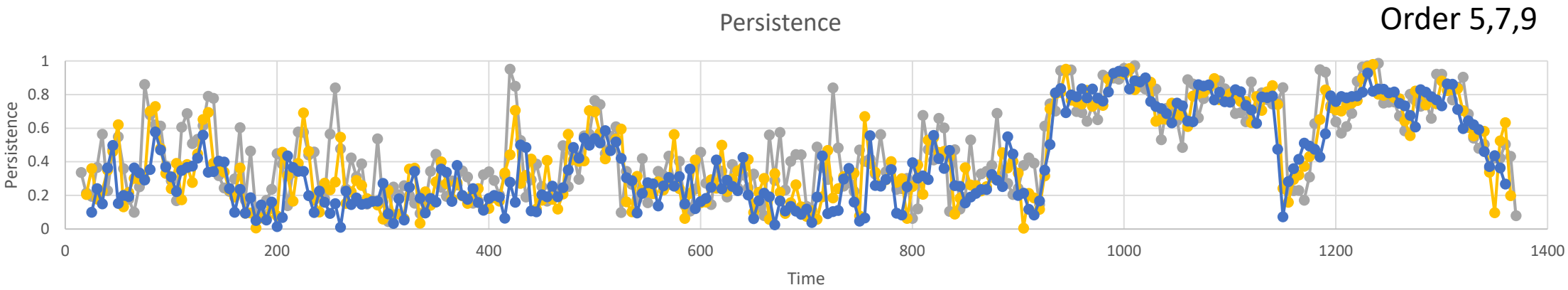
How can we recognize the above observations from the tracking data?

Application to the trajectory of the MS-1 cell





Application to the trajectory of the MS-1 cell



We can evaluate the change of persistency.

About *t*=900, the MS-1 cell begins to move in a definte direction;

About t=1150, it turns to another direction.

Conclusion

- We propose a criterion for the persistence of cell movement especially for very-slowly-moving cells, e.g. the MS-1 cell.
- It successfully reveals the change of the persistence in the course of time.

Thank you for your attention!