System-wide organization of actin cytoskeleton determines organelle transport in hypocotyl plant cells

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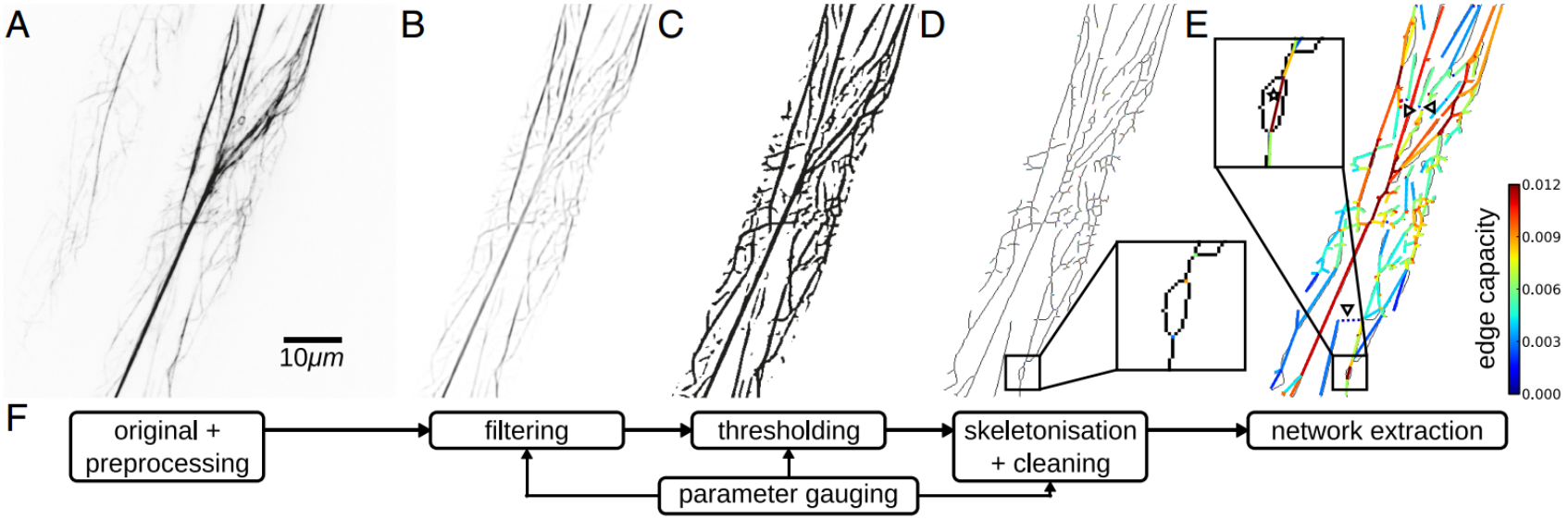
backgrounds

- 狭义的细胞骨架*(cytoskeleton)*概念是指真核细胞中的蛋白纤维网架体系*(微管（microtubule, MT)*、微丝*(microfilament, MF)*及中间纤维(intermediate filament, IF)组成的体系

- 微丝主要由肌动蛋白（actin）构成，和肌球蛋白（myosin，一种分子马达蛋白）一起作用，使细胞运动。它们参与细胞的变形虫运动、植物细胞的细胞质流动与肌肉细胞的收缩等

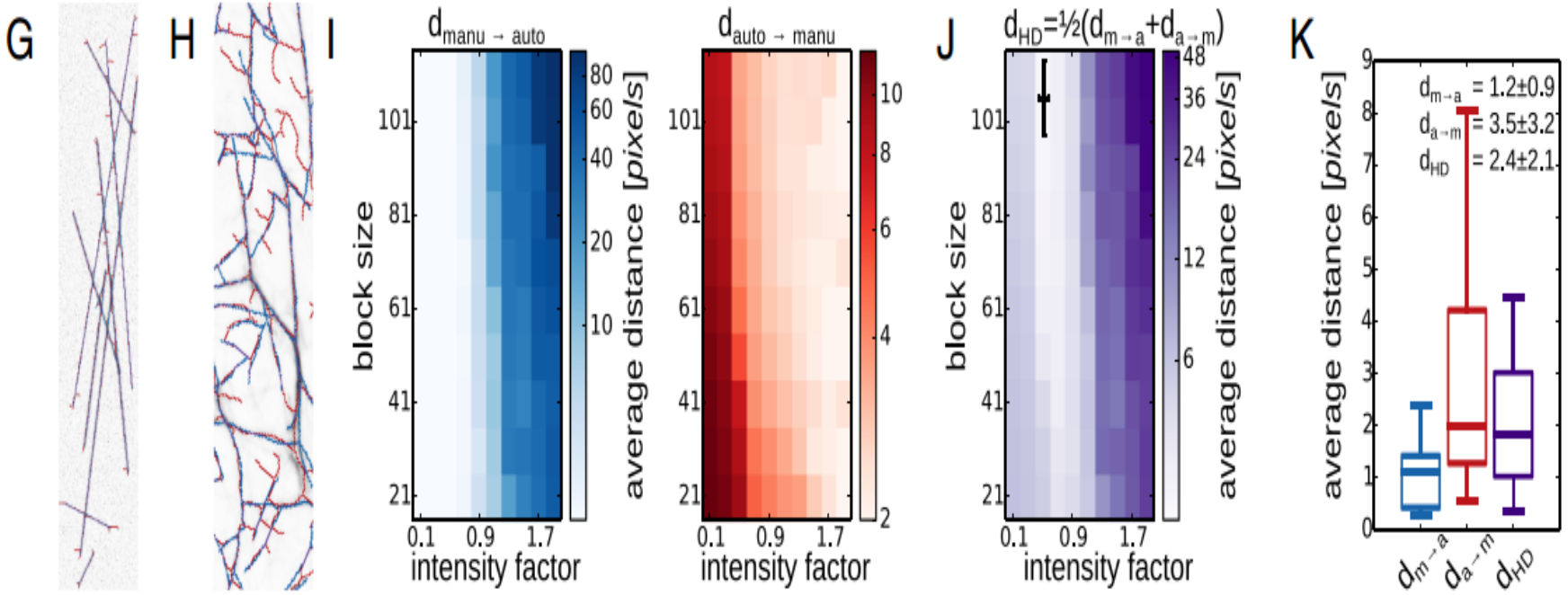
- 单体的肌动蛋白是由一条多肽链构成的球形分子， 又称球状肌动蛋白，外形类似花生果。肌动蛋白的多聚体形成肌动蛋白丝， 称为纤维状肌动蛋白。在电子显微镜下，纤维肌动蛋白呈双股螺旋状， 直径为8nm, 螺旋间的距离为37nm

A Pipeline to Extract and Represent the Actin Cytoskeleton as a network



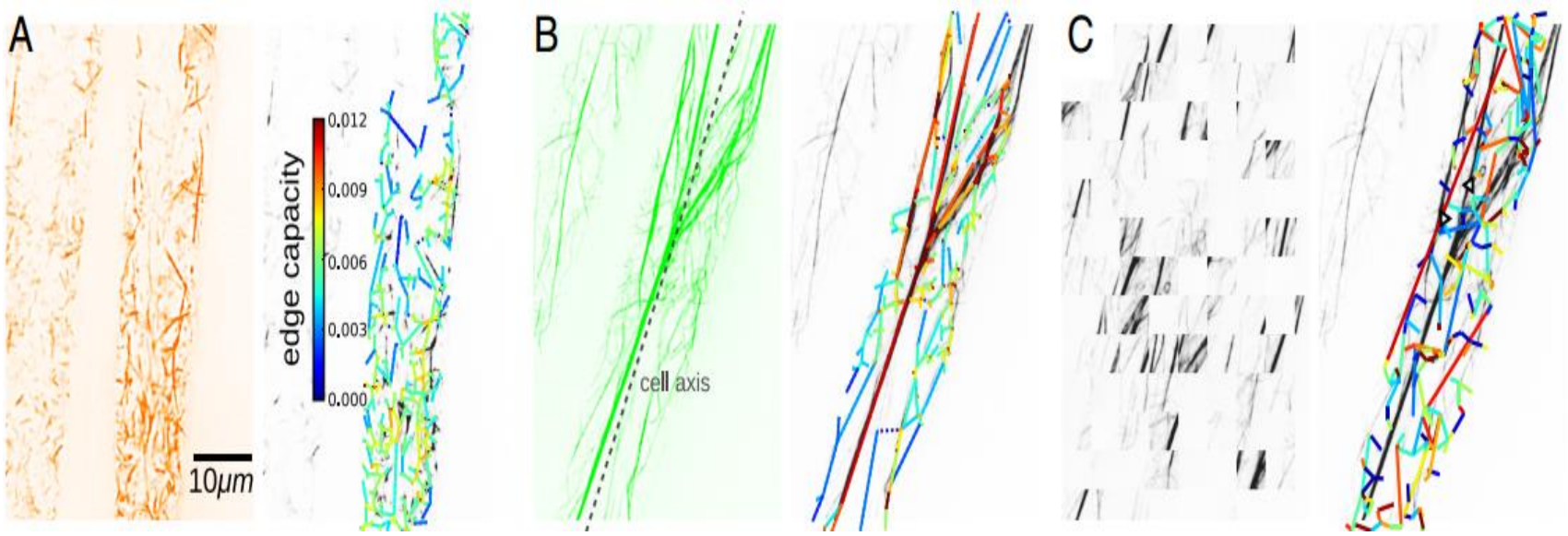
➢**Networks** were obtained by identifying the **nodes**,adding **edges** between pairs of nodes directly connected via the skeleton, and assigning **edge weights** reflecting features of AF segments, e.g., average thickness (Fig. 1*E*).

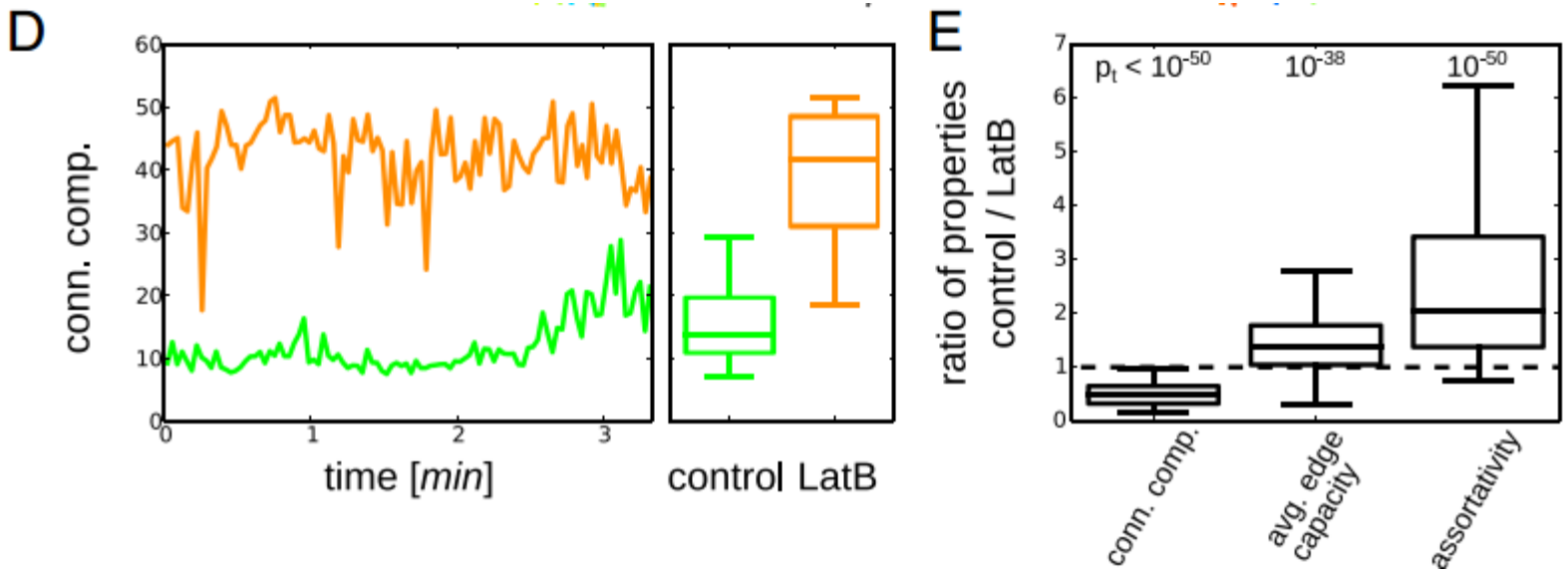
compared **automated segmentations** against **synthetic images** of known cytoskeleton-like structures as well as **manually segmented cytoskeleton images**



- *(v*width ∗, *v*thres ∗, *v*size ∗, *v*int ∗) = (1.8, 101, 27, 0.50) ± (0.2, 8.0, 8.9, 0.06) (mean ± SD)
- *d*manu-auto = 1.2 ± 0.9 pixels, *d*auto-manu = 3.5 ± 3.2 pixels, and *d*HD = 2.4 ± 2.1 pixels

The Network Representations Capture Biologically Relevant Features of the Actin Cytoskeleton

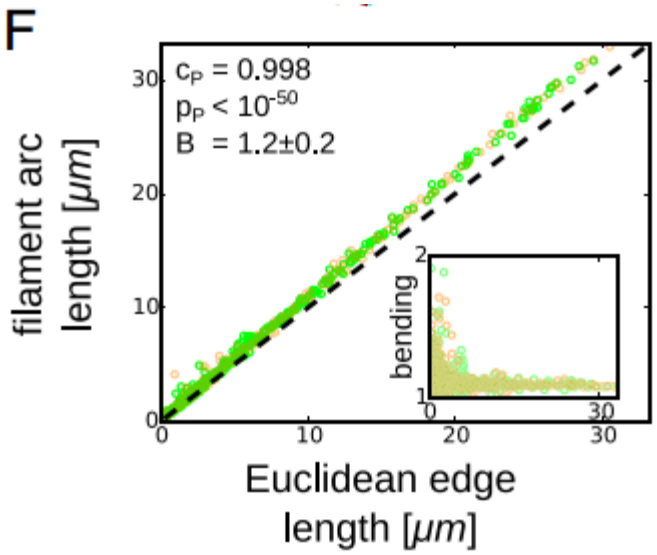


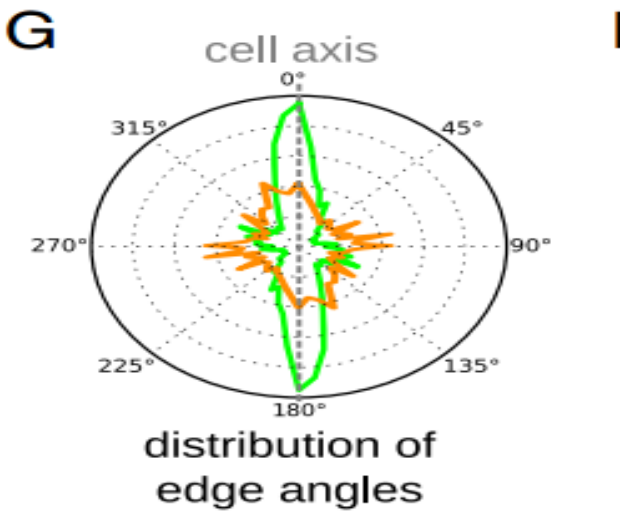


➢Fragmentation was lower in networks of control than of LatB-treated cells, indicating that large connected patches of Afs were absent in LatB-treated cells, consistent with visual inspection.

➢ the average edge capacity was higher in control than in LatB-treated cells , reflecting a reduction in actin bundling in the LatB-treated cells

➢Finding that stronger heterogeneity for control than for LatB-treated cells (*Pt* < 10-50), suggesting regions of bundled actin that are surrounded by AFs in the control cells

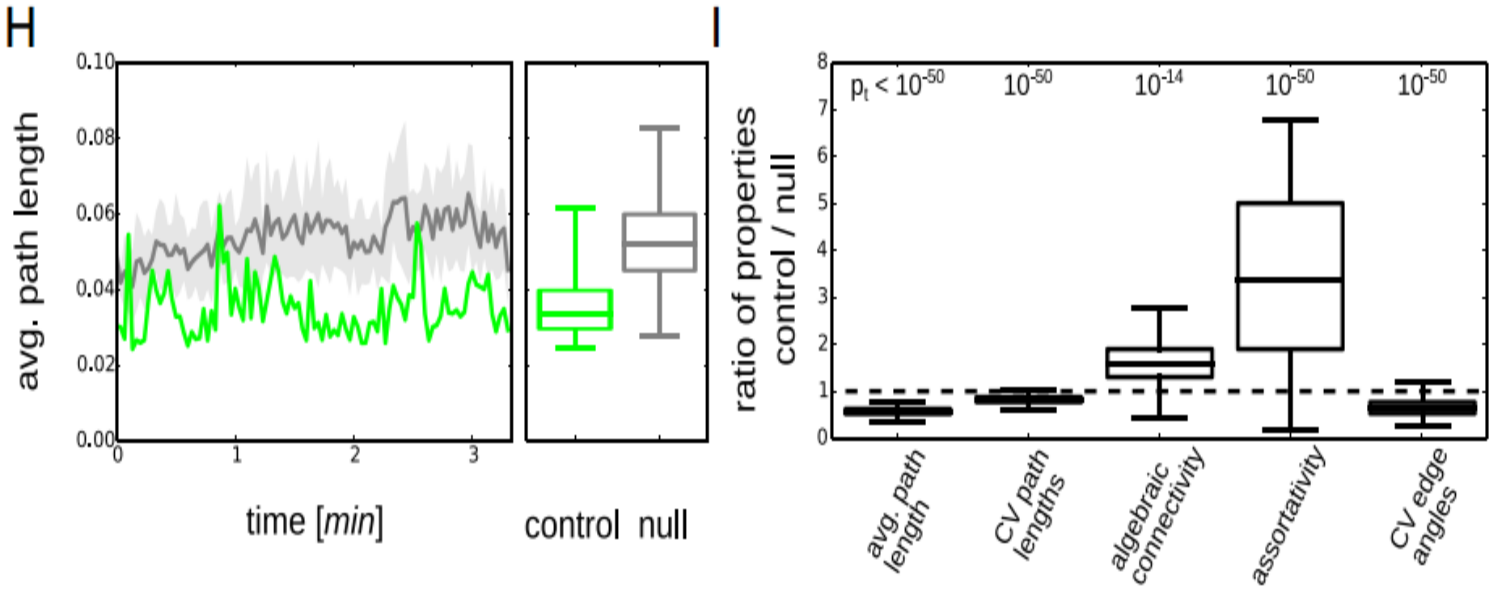




- To demonstrate the robustness of our findings, we showed that the differences in network properties between control and treatment were not affected by removal of a random fraction of edges, simulating effects of erroneous network extraction

- comparing cytoskeletal networks in hypocotyl cells at different developmental stages

- Difference in growing hypocotyl cells (the untreated control showed stronger fragmentation and weaker bundling than in their LatB-treated counterparts)

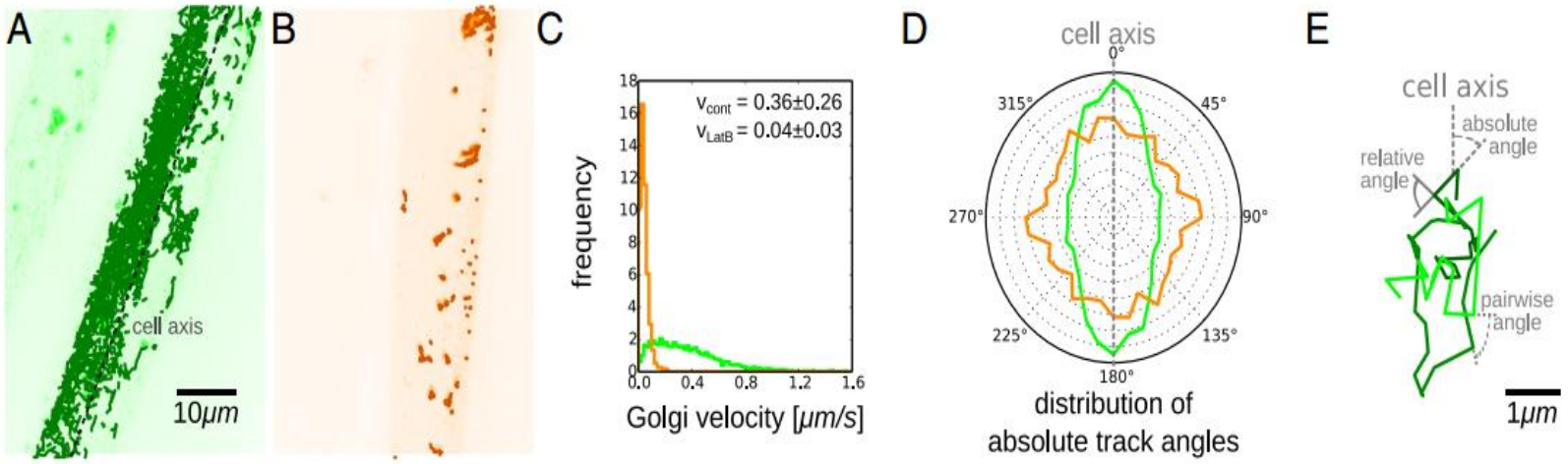


➢Founding that the average path length of the extracted networks was smaller than that of the null model networks ,which indicates that the actin cytoskeleton is tuned toward shorter path lengths.

➢ In contrast, the LatB-disrupted actin cytoskeletons did not show any significant differences in their transportrelated network properties compared with the null model networks .

➢In summary, our analyses indicate that transport efficiency is a central design principle of the actin cytoskeleton in hypocotyl plant cells.

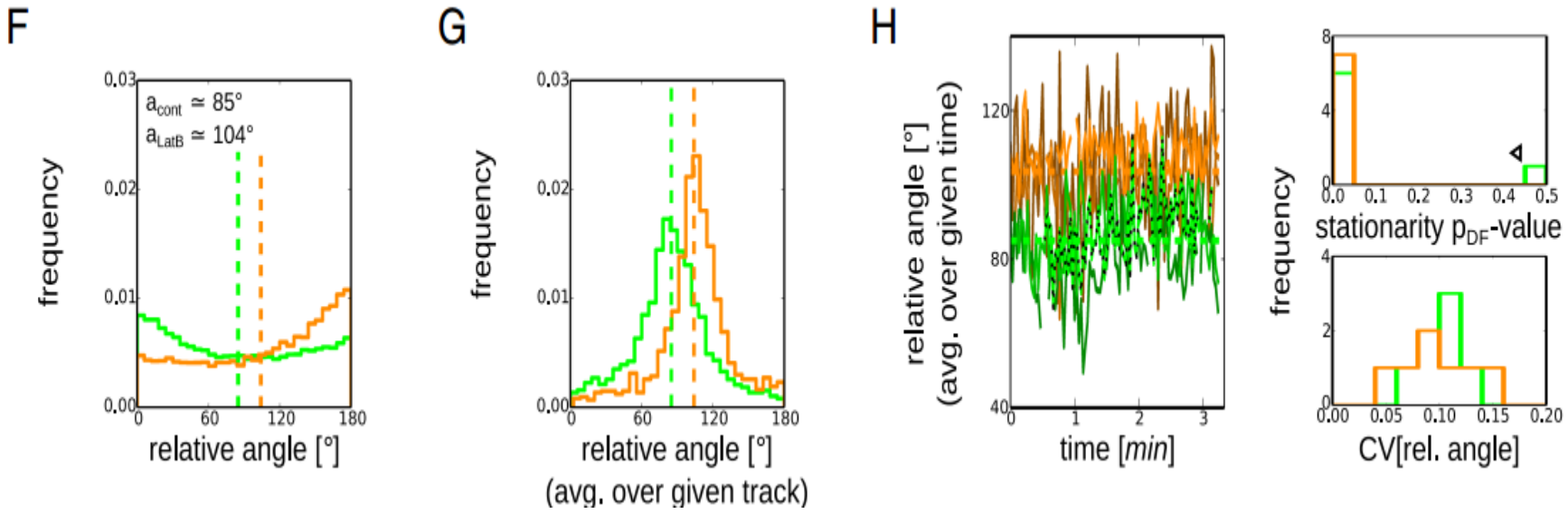
Automated Quantification of Golgi Movement



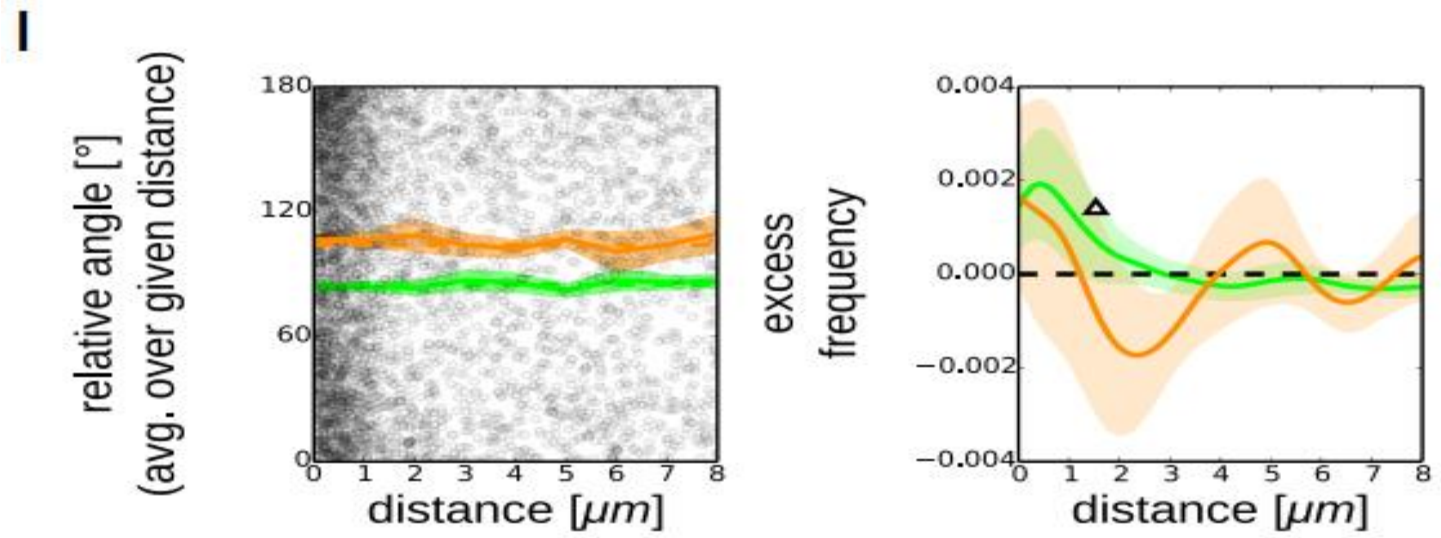
➢Golgi bodies moved with velocity is higher in untreated cells than in LatB-treated cells.

➢ The Golgi movement was predominantly parallel to the major cell axis in control cells but not in LatB-treated cells (Fig. 3*D*),correlating with the orientation of actin bundles (compare withFig. 2*G*)

➢Thus, our automated tracking captures known features of Golgi movement and may therefore be suitable for further,more detailed analyses of Golgi behavior



- confirming that wiggling behavior is not specific to individual Golgi
- wiggling behavior is not specific to individual Golgi
- Golgi wiggling is a common and stable cellular phenomenon

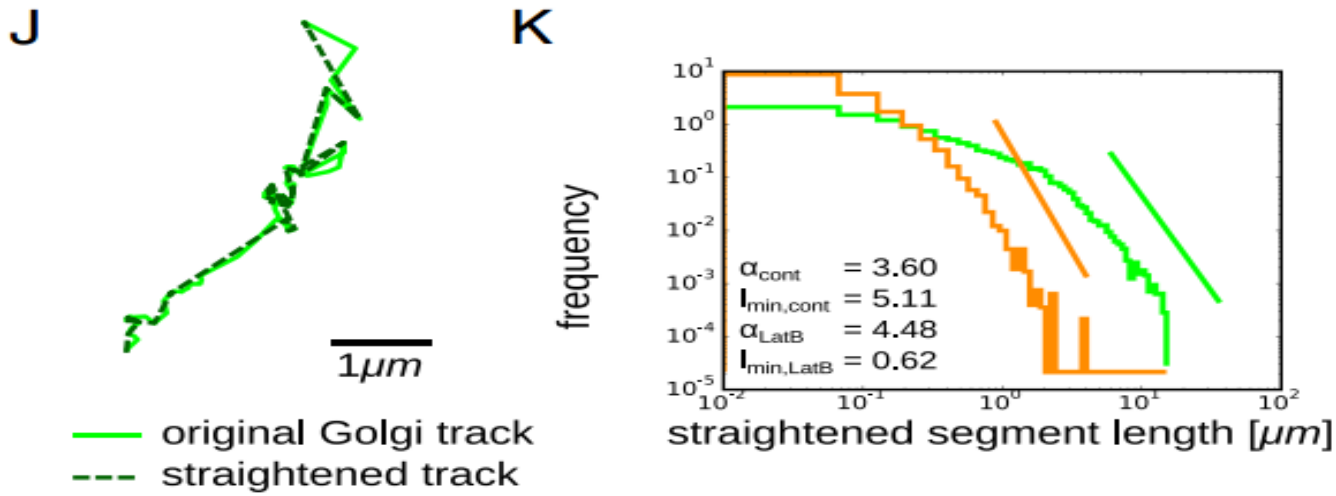


➢The frequency of Golgi was dependent on the distance to the AFs ,with high Golgi densities up to 2 µm from the AFs

➢the prevalence of Golgi wiggling did not depend on the distance from the Afs or on their thickness

➢the features of Golgi movement studied here were highly consistent across cells

Movement Patterns of Golgi Resemble Search Strategies and Might Optimize Uptake and Delivery



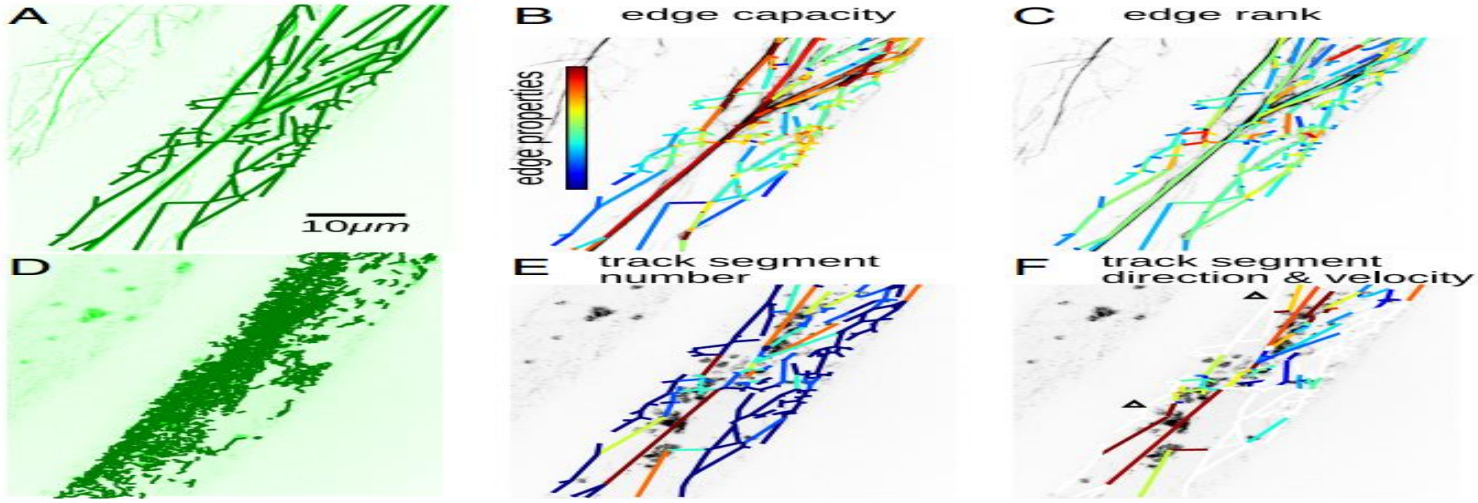
$$p(l)=\frac{\alpha-1}{l_{min}}\left(\frac{l}{l_{min}}\right)^{-\alpha}$$

- might indicate search strategies in small areas with a limited number of targets or in the presence of obstacles or preferred areas

- Again, these findings were highly consistent across cells

- switching of Golgi to adjacent AFs is myosin dependent, whereas switching to nonadjacent AFs is due to cytoplasmic streaming that may carry the Golgi over large distances.

Local and Global Actin Network Architecture May Be Used to Predict Direction and Velocity of Golgi Movement



- edge degree(measuring the total thickness of adjacent edges)

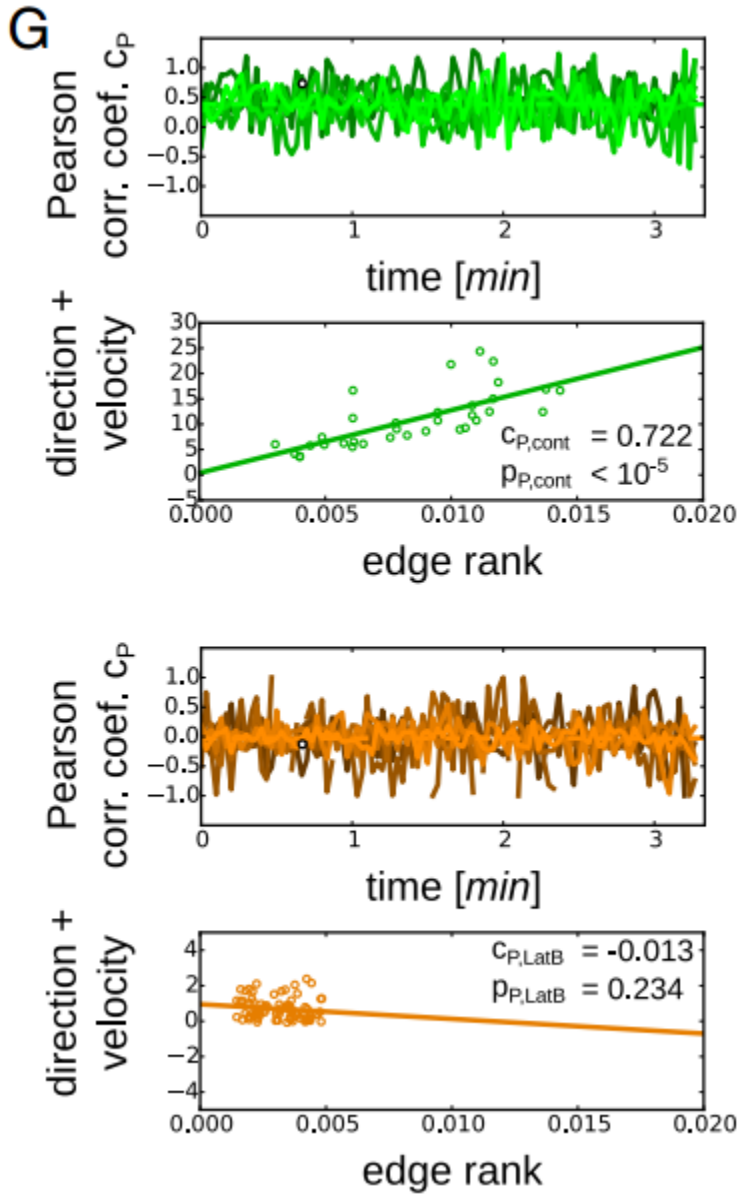
- the edge page rank (measuring the probability that cargo that randomly traverses the network is found at the given edge)

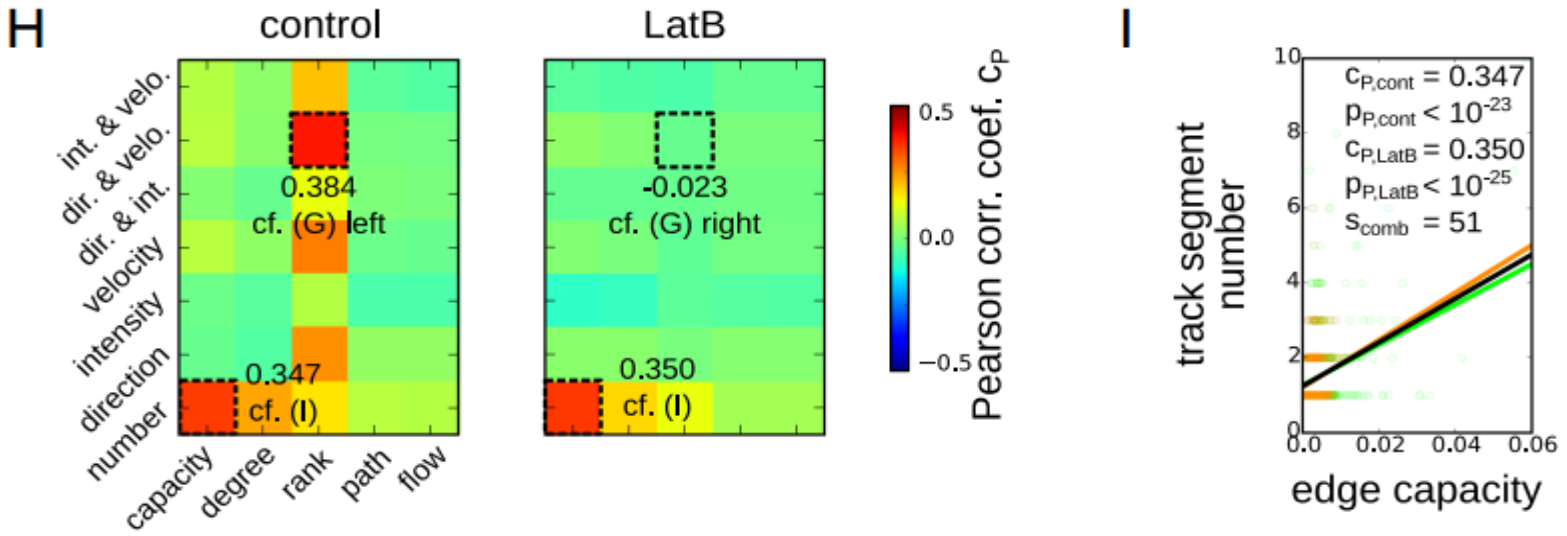
- edge path betweenness (measuring the likelihood that the given edge lies on a shortest path through the network)

- Edge flow betweenness (measuring the total maximum flow between any two nodes through the given edge)

➢we studied the dependence of the Golgi direction and velocity on the actin edge rank. The correlation between the two properties varied over time and across cells (Fig. 4*G*). Across all studied partiallyelongated cells, this correlation was significant for control cells with *cP* =0.384, whereas no significant correlation was found for the LatB-treated cells with *cP =-0.023.*

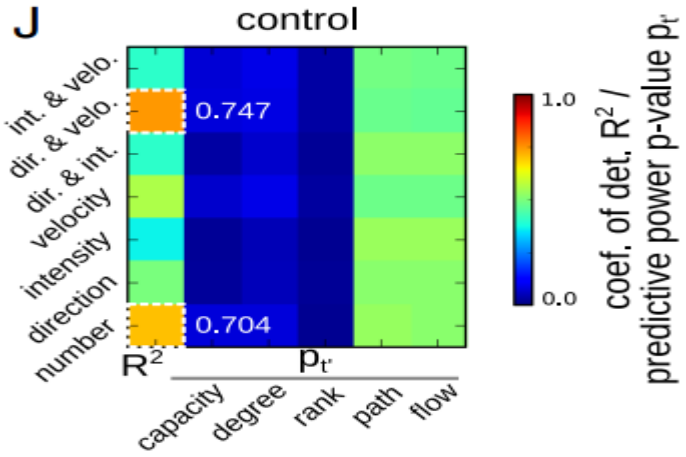
➢These findings are compatible with the severely reduced flow (Fig. 3*C*) and increased wiggling behavior of Golgi (Fig. 3*F*) in LatB-treated cells.





➢for most pairs of actin and Golgi flow network edge properties, there was no or only weak correlation ($|cP| \leq 0.2$)

➢Hence, whereas in particular, edge flow and path betweenness have been suggested to predict transport in real-world networks (55–57), they were not predictive of Golgi transport along the actin cytoskeleton in hypocotyl plant cells .



➢the number of Golgi close to an actin edge(Fig. 4*K*; coefficient of determination *R*2 = 0.704) and the Golgi direction and velocity (*R*2 = 0.747) were accurately predicted

➢edge capacity, edge degree, and edge rank of the actin network had higher predictive power .

➢As edge capacity and edge degree reflect (semi)local actin bundling, their observed high predictive power supports the finding that actin bundling is correlated with Golgi density and velocity .

➢these correlations between actin structures and Golgi movement were very similar for growing and fully elongated hypocotyl cells .

➢Therefore, the system-wide organization of the actin cytoskeleton in hypocotyl cells shapes, and may be used to predict, the dynamic flow of Golgi .

文章的创新、亮点：

使用基于图像的算法自动提取肌动蛋白骨架结构，并构建网络，用系统生物学的思维，量化网络中各种属性来研究肌动蛋白细胞骨架，及其对细胞器转运的作用

文章可以改进的的地方、不足：

文章中某些结论的得出猜想性成分较多，如在研究高尔基体的运动模式中得出的该运动模式能最优化高尔基体的吸收和释放物质过程，没有具体的量化指标，也没有实验支撑，只是结合文献理论猜想，猜想需进一步认证。

启发：

科学研究需要多学科的交融，用系统的思维方法来分析生物学问题能让我们对生物学问题得以量化分析。

可借用该文章思路，构建相似流程，来分析其余动植物细胞中中肌动蛋白细胞骨架或者微管、中间丝细胞骨架系统。

Thanks!