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The Propagation Problem

What the Tallest Trees Know About the Limits of Containment

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The tallest trees on Earth stop growing at roughly the same height. Coast redwoods, mountain ash, and the tallest eucalyptus all approach a similar limit, a little over 115 meters. The wood could support more weight. The canopy could capture more sunlight. The soil could anchor a larger trunk. What stops the tree is hydraulic. Water inside the tree is under tension, pulled upward from the roots by evaporation from the leaves. As height increases, the tension required to lift that water increases with it. At a certain point the tension approaches the threshold where bubbles form and the hydraulic pathway fails. The tree stops growing because the water cannot travel further without breaking.

I. The Limit Is Not What It Appears

Engineers studying tall trees expected to find the limiting factor in the obvious places. Wood strength. Root anchorage. Nutrient transport. Each of these imposes a ceiling, and none of them is the one that matters at extreme height. The limiting factor is hydraulic. Specifically, it is the stability of the water column under tension.

Water in a tall tree is pulled upward by evaporation from above, a process called transpiration. The water column is under negative pressure, which is to say tension. At sea level the atmospheric limit on this mechanism is well understood. Trees face an additional constraint that the atmosphere does not impose: gravity. Every meter of additional height requires more tension to lift the water that far. The tension accumulates with height.

At some point the tension in the water column approaches the threshold where dissolved gases come out of solution and form bubbles. Engineers call this cavitation. A bubble in the water column breaks the hydraulic pathway. The connection between roots and leaves fails at that point. The tree cannot supply water to the canopy. Growth stops. In sufficiently severe cases the tree dies from the top down.

The maximum height of trees is therefore set by what the hydraulic system can propagate without breaking, not by what the structure can bear. The tallest possible tree is the tree at the edge of cavitation stability.

II. Why Containment Fails at Height

The previous essay in this series described how trees survive disturbance by building thousands of small conduits instead of a few large ones. Small conduits contain embolisms locally. The failure cannot cross the pit membranes between conduits. The system continues functioning around the damage.

At extreme height something changes in the propagation dynamics. The tension in the water column is so high that cavitation risk is elevated throughout the system. A disturbance that would have remained local at lower heights now propagates more easily, because the water everywhere is closer to the cavitation threshold. The containment architecture has not changed. The propagation conditions have.

This is the critical insight. Containment architecture limits propagation under normal conditions. At extreme height, the conditions themselves change the propagation dynamics. The same membranes that stopped embolisms at 60 meters are less effective at 115 meters, because the driving force behind propagation has increased. The system is now running near the edge of what its containment architecture can absorb.

Beyond that edge, disturbances propagate faster than the system can contain them. The tree cannot grow taller because it cannot maintain propagation stability at greater height. The limit is not a structural threshold. It is a propagation threshold.

III. The Threshold

Physicists studying cascade failures and network propagation have identified a class of phenomena governed by critical thresholds. Below the threshold, disturbances are absorbed locally. They spread a short distance and stop. The system returns to its baseline state. Above the threshold, disturbances propagate through the entire system, and a single local failure can reach every connected part of the network. The system does not degrade gradually past the threshold. It changes regime.

The transition between these two behaviors is sharp. What changes at the threshold is not the size of the disturbance. It is the ratio between propagation speed and the system's capacity to absorb it. When that ratio crosses one, local failures become systemic ones.

Trees live just below this threshold. Their hydraulic architecture is calibrated to keep cavitation propagation slow enough that the system can absorb it. The maximum height of a tree is the height at which that calibration still works. One meter taller and the ratio tips, and the system crosses into the regime where disturbances span the network.

The consistency of the height limit across species is a physical law, not a biological accident. The threshold is set by the tension physics of water under gravity, and every tall tree encounters it at roughly the same point.

IV. Systems That Cannot Stop

Below the threshold, a disturbance leaves room to respond. It spreads a little, slows, and stops, and the parts of the system around it have time to react before it reaches them. Above the threshold, that room is gone. The disturbance moves through the system faster than any local response can be brought to bear against it.

The people inside the system can often still see what is happening. The failure is not hidden. But seeing it is no longer the same as being able to stop it. A correction made at one point lands on a disturbance that has already moved past that point. Each response is aimed at where the problem was, not where it now is. The system can produce one accurate local correction after another and still lose the race, because the disturbance is traveling faster than the corrections can be formed and applied.

This is the change that the threshold marks. It is not that the disturbance grew larger. It is that the system stopped being able to catch it. And once that happens, the thing that started the disturbance stops being the part that matters most. Whatever the initiating event was, it is no longer what explains the outcome. What explains the outcome is that the system could not arrest the spread.

V. Why Some Systems Cross and Others Do Not

If the spread is what matters, then it is worth asking why the same disturbance spreads in one system and not in another.

It does. The same kind of failure, entering at the same kind of place, stays local in one structure and runs through the whole of another. The disturbance is the same in both. The outcome is not. That difference cannot be coming from the disturbance, because the disturbance did not change. It must be coming from the system that received it.

The threshold therefore cannot belong solely to the event. Something about the receiving structure must also matter. Two systems meeting the same disturbance can sit on opposite sides of the line, one absorbing what the other transmits, and the only thing that differs between them is how they were built. That makes the location of the threshold something each system brings with it, set before any disturbance arrives. Where that location comes from, and whether anything can move it, is the question the next section takes up.

VI. What Determines the Threshold

For trees, the threshold is set by the physics of water under tension and the geometry of the conduit network. Engineers cannot change the physics. They can observe where the threshold lies and design accordingly.

For institutions, the threshold is set by the density and non-compensability of the boundaries that interrupt propagation in the decision architecture. Unlike the tree's physics, this is designable. The threshold can be raised by adding structural boundaries. It can be lowered by removing them. Every time a verification stage is compressed, every time authority is centralized, every time a non-overridable evaluation stage is made overridable, the threshold moves. The institution sits closer to the propagation regime where local failures become systemic ones.

This is what makes the institutional version of the problem harder than the hydraulic one. Trees cannot choose to grow taller than their physics permits. Institutions choose, repeatedly and under pressure, to remove the boundaries that determine where their threshold sits. Each choice is made under the same logic: the boundary slows things down. The choice looks like efficiency. The threshold moves, and the system does not register the change until a disturbance arrives that the reduced architecture cannot absorb.

By then the ratio has already crossed one. The disturbance propagates. The failure spans the system. Observers identify the disturbance as the cause. The architecture that had been quietly recalibrated over months or years does not appear in the incident report.

VII. The Rule

Systems under continuous flow stay stable only while disturbances propagate more slowly than the system can absorb them.

That ratio is the governing variable. Everything else follows from it. The height of trees. The stability of power grids. The integrity of decision architectures under pressure. All of them are governed by the same relationship between propagation speed and absorption capacity.

The systems that survive disturbance are not the ones that prevent disturbances from occurring. They are the ones that keep the ratio below one. They do this through architecture, through the density and non-compensability of the boundaries that slow propagation before it reaches the next stage. Those boundaries are not inefficiencies. They are the mechanism by which continuous operation stays stable.

Trees reach their limit at 115 meters because the physics will not allow the ratio to stay below one any further. Institutions reach their limit when they remove enough structural boundaries that ordinary disturbances cross the same threshold.

The tree cannot choose where its threshold sits. The institution can. That is the only difference. It is enough.