Unraveling the Mysteries of Congestion

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Anyone who has driven on highways understands that random events affect congestion. Even in relatively light traffic, with no accidents or obstructions, cars will suddenly bunch up, slow, and then speed up again.

Ward Whitt studies the enigma at the heart of this process. His discipline—queueing theory—examines how random fluctuations in flow, waiting, and processing cause congestion in complex systems.

Examples are everywhere. "We all spend too much time waiting on lines, from physical lines in a supermarket or bank to invisible lines on hold for a call center or waiting for a web page to load," Whitt said. Queues are equally present in the waiting times of a computer processor or the movement of parts through a factory.

One major goal of queueing theory is to reduce waiting. Understanding congestion helps engineers specify the right number of telephone switches, Internet servers, and even call center personnel.

Despite their wide use, queuing models have a significant weakness. "The standard queueing models assume random flow, but the rate of that random flow is assumed constant. In reality, the arrivals to a system occur randomly, but the rate of that random flow is not constant," Whitt said.

Whitt tries to capture that systematic variation in the flow rate together with the uncertainty about that flow rate. He builds and analyzes models that reflect both these features of everyday queueing phenomena. "This produces high fidelity descriptions of congestion that go far beyond standard textbook queueing models," he said.

Whitt is also applying these insights to complex networks. "Queues do not appear in isolation, but appear in networked systems with multiple flow paths and queues," he said.

One way to tackle complex, networked systems is to see how they would behave as they scale up. "Sometimes," Whitt said, "a larger model tells a clearer story. Toss a coin 20 times and you expect to average 10 heads and 10 tails, but you may see from seven to 13 heads. But toss the coin one million times, you are likely to get closer to a 50-50 split."

He has developed mathematical techniques that show how congested systems behave at larger scales. He then compares the model with computer simulations of the system or data from that system.

"When you do this, you can end up with a fairly simple story that tells you a lot about your system," Whitt said.

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