Alejandro Ribeiro

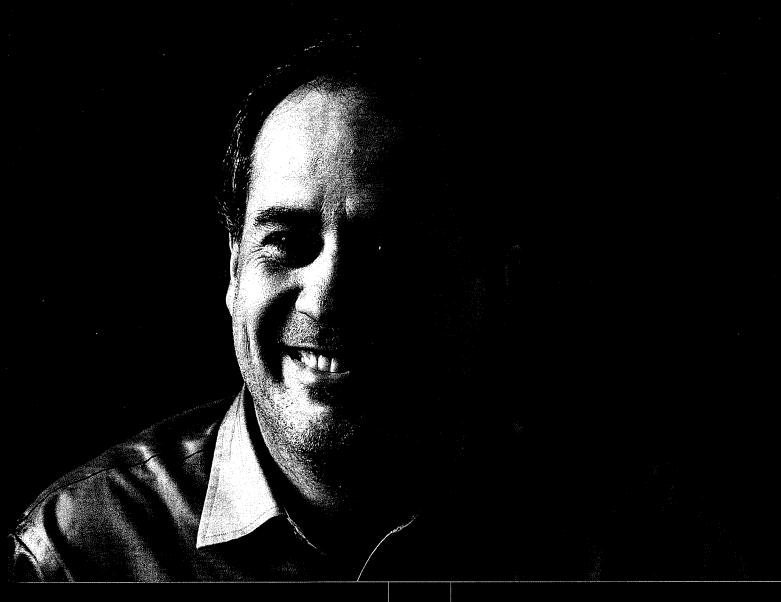## EXPANDING APPLICATIONS OF NETWORK SCIENCE

The real power behind a network, says Alejandro Ribeiro, isn't its component parts. It's the myriad ways they connect with one another. The social bonds we share with others. The flow of information that makes the internet possible. Even the tiny electrical impulses that appear between neurons in the brain, letting us think, feel, taste, touch and interact with the rest of world.

As an associate professor in the Department of Electrical and Systems Engineering, Ribeiro uses complex mathematical frameworks to understand how networks behave. Instead of looking at individual points in that network, he examines what's going on between those points. "It's really about the connections each point shares with others. If a single data point is a city on a map, we're looking at the highways that run between each of those cities," says Ribeiro.

SHAKESPEARE'S WORK?

The plays of William Shakespeare are just one area where Ribeiro's work is proving useful. Although 500-year-old literature may seem an unlikely place for mathematical analysis, the field could help settle one of the thorniest mysteries surrounding the works—whether or not Shakespeare actually wrote all of them.

The Bard's Henry IV plays have been particularly suspect, but until now, there hasn't been a rock-solid way to confirm their authorship. Ribeiro's work is changing that. The process involves an emerging technique called "Graph Signal Processing," or GSP, which he has pioneered over the past several years. Along with colleagues at MIT and De Montfort University in the U.K., he created what he calls a "word adjacency network" for each of the plays, taking stock of words that appear in all of them. Rather than focusing on descriptive words that

determine a play's content, however, he used GSP to analyze the relationship between words like "the," "and," "a" and "to," scrutinizing the connective tissue of each work.

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"It's not just about the number of times each word appeared, it's about the order. Sometimes there's a difference in those relationships," he says. In some plays, for example, the word "they" appears more often in a sentence sometime after the word "a" is written; in others, it might come after the word "the" appears. By looking at those relationships, Ribeiro says, it's possible to create a fingerprint for an author's style, and by extension, their identity.

Through his analysis, Ribeiro was able to show that most of The Bard's works corresponded with his usual style, but a few outliers didn't. Parts of Henry VI, for instance, were strongly associated with word patterns used by Christopher Marlowe, one of Shakespeare's contemporaries, meaning that the play could have been a collaboration.

ROBOTIC SWARMS

The complex relationships Ribeiro is teasing out of Shakespeare's plays might also be applicable to a completely different field: swarm robotics. In the future, groups of tiny robots may be able to communicate and work with one another, like a colony of ants, to meet a shared objective such as delivering packages or inspecting a bridge.