

## CORRESPONDENCE PATTERNS

## Mechanisms and models of human dynamics

Arising from: J. G. Oliveira & A.-L. Barabási *Nature* 437, 1251 (2005)

A stochastic queue model of human behaviour developed on the basis of the distribution of timing of tasks, as studied in a sample of e-mail messages at a university<sup>1</sup> and in the written correspondence of Albert Einstein<sup>2</sup>, may not be as simple as it seems. Although this model reproduces the apparently non-Poisson distribution of correspondence delays, its interpretation is more complicated than suggested by Barabási, who claims that humans execute their tasks based on some perceived priority, setting up queues that generate very uneven waiting-time distributions for different tasks<sup>1</sup>. Such an explanation is intuitively appealing in the context of the queue metaphor, but does not exclude other mechanisms. By attributing delays in the correspondence to task priorities, this explanation ignores two important classes of mechanism that also contribute to the apparent distributions of task timings: the semantic content of an individual's correspondence and the social context in which this correspondence occurs.

For example, Oliveira and Barabási use Albert Einstein's two-year delay in correspondence with Theodor Kaluza as an illustration of the 'priority list' model<sup>2</sup>. Although it is true that Einstein did not communicate Kaluza's work to the Prussian Academy of Sciences until two years after Kaluza first sent his manuscript to Einstein, this was not due to a perceived unimportance of the task by Einstein. Rather, on 21 April 1919, Einstein wrote a prompt reply acknowledging the receipt of Kaluza's manuscript just a few days earlier<sup>3</sup>. On 29 May 1919, Einstein suggested that Kaluza should revise his current manuscript to resolve a flaw in his unified field theory, and encouraged Kaluza to submit the work for publication in *Mathematische Zeitschrift*, even offering "to put in a good word" with the editors<sup>3</sup>. To help Kaluza, he enclosed a manuscript of his own that related the electromagnetic and gravitational fields<sup>4</sup>.

Kaluza attempted to address the flaw pointed out by Einstein, but ultimately was unable to, referring to it as a "serious difficulty" in the final version published in 1921 (ref. 5). Thus, the delay between Einstein's receipt of Kaluza's original manuscript and its final publication was probably due to the difficulty that Einstein's question posed for Kaluza, and not to the low priority that Einstein assigned either to replying to Kaluza or in recommending his manuscript for publication.

Even when questions posed in letters are easy to answer, responses and their consequent actions may be delayed because they are part of a many-person conversation and require information from other interlocutors. For

example, the distribution observed for e-mail delays<sup>1</sup> may be due to groups of individuals engaging in shared conversations, in which individuals send messages not according to personal priorities, but rather to their collective attributes such as kinship, hierarchy and affiliation. Earlier analysis of the e-mail data set used by Barabási revealed significant many-person conversations, as reflected in the temporal coherence of three-person e-mail exchanges<sup>6</sup>. These social structures and their temporal correspondence properties were due to groups of individuals who were affiliated with academic departments, comprised non-academic committees, and shared common foreign nationalities<sup>6</sup>. Their existence is consistent with the idea that the mechanism underlying the apparent non-Poisson distribution of e-mail timings is related to the collective properties of the inherently social groups that produce them.

In all communications, both the semantic content of tasks, as in the correspondence between Einstein and Kaluza, as well as their social context, as in the correspondence of e-mail users, are important factors in the mechanics of human interaction. The stochastic queue provides a useful model and an elegant metaphor for the interdependence of

human tasks, but this does not mean that it is determined by individual priority lists. Indeed, the priority queue metaphor could be replaced by a semantic ladder or social web, depending on the nature of the variable (personal priority, task difficulty or social relevance, respectively), that parameterizes the model's response time. Determination of the mechanism(s) underlying the apparent distribution of human task timings requires precise investigation of the relationships among the semantic content of tasks, task priorities as perceived by individuals, and the collective attributes of the social groups that govern human behaviour.

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*Barabási & Oliveira reply*Replying to: A. Kentsis *Nature* 441, doi:10.1038/nature04901 (2006)

Kentsis notes that the response time to an e-mail or a letter depends on the semantic content of the correspondence, as well as the social context in which the communication arises<sup>1</sup>. We would add that it also depends on deadlines, the time dependence of priorities and the dropping of past-deadline messages<sup>2</sup>, making human response dynamics sufficiently complicated that no simple model could fully account for it<sup>3–6</sup>. However, the advantage of the proposed modelling framework is that most of these effects can be incorporated into it, and their impact on the queuing process can be systematically evaluated. Addressing some of these additional mechanisms, including those suggested by Kentsis, requires information that is beyond reach for most researchers at this point.

Thanks to legitimate concerns about privacy, we do not have access to the text of e-mail messages, which limits our ability to analyse

both the semantic and the social context in an automatic fashion. But it is not impossible to envisage advances in these directions, given that important e-mail services (such as gmail) analyse message content for the purpose of placing advertisements, as well as using algorithms developed in the context of interruptibility research to evaluate both content and social context<sup>7</sup>. The proposed models thus represent the starting point for a quantitative understanding of human dynamics.

The comment raises an important question: given that so little information is available for several key parameters, why are the proposed models so successful at capturing the observed response-time statistics, for both e-mails<sup>3</sup> and letters<sup>4</sup>? To understand this, we note that message content, social context and deadlines are important only for assigning the correct priority to each message. However, it can be shown that the response-time distribution is inde-

pendent of the priority distribution<sup>3</sup>. Therefore, to predict the response statistics correctly, we do not need to know the correct priority of each message, but any priority distribution will lead to the same response-time distribution.

Given this fact, we can distinguish two goals of potential interest. One is predicting the response statistics of the overall communication pattern, at which queuing models are excellent, even without information on social context, message content and the precise value of the priorities assigned to each message. The second is predicting the precise response time to a specific message, which will require an evaluation of all factors that have an impact on the specific message. In other words, without knowing all the circumstances of the

Kaluza–Einstein correspondence, including Einstein's and Kaluza's competing responsibilities, it would be impossible to foresee the two-year delay in the publication of Kaluza's famous paper. Yet we can accurately predict the fraction of letters that waited for one day, one month or one year on Einstein's desk before he would write a response, as — amazingly — the response-time distribution is completely independent of the individual priorities assigned to a letter. This universality and independence of details is the real strength of the proposed modelling framework.

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