all polymers (see the figure). Although Zhou *et al*. have made an appreciable step toward eliminating the costly vacuum deposition of low–work function metal electrodes, there is still much work to be done before low-cost roll-to-roll printing of organic electronics is fully realized.

The long-term stability and device lifetime of low–work function PEI-modified electrodes needs to be examined in various organic electronic devices. The preliminary lifetime testing data reported by Zhou *et al*. for an organic solar cell are promising, but longer-term testing on packaged devices operating under real conditions needs to be performed to ensure that the electrodes are stable for the lifetime of any commercial product in which they may be used. From a practical point of view, it is still not clear whether scale-up of solution-processing techniques for organic electronics to mass production is truly viable. For example, state-of-the-art flat-panel displays are manufactured on large-area substrates (2.2 m × 2.5 m); to date, only vacuum-processing techniques can handle such substrates with adequate uniformity, yield, and throughput time. Nonetheless, with the strong and growing momentum behind organic electronics, the present barriers to low-cost flexible devices are poised to be overcome in the near future.

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10.1126/science.1220829

PSYCHOLOGY

Tapping into the Wisdom of the Crowd—with Confidence

The subjective confidence of individuals in groups can be a valid predictor of accuracy in decision-making tasks.

Ralph Hertwig

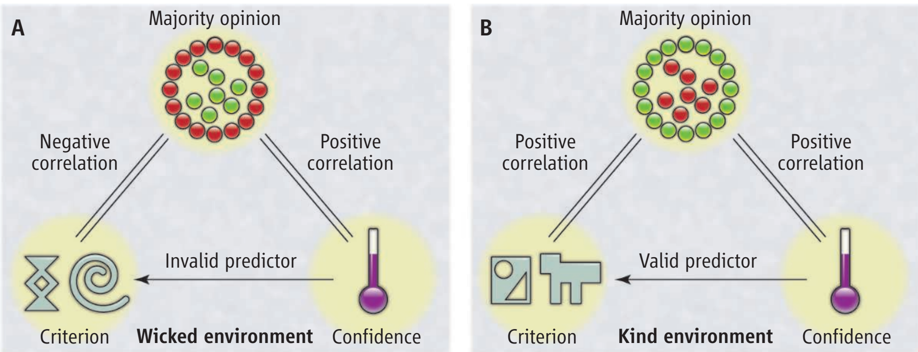
If research in psychology had a Dr. Jekyll and Mr. Hyde Award, it would go to—drum roll, please—the group as a decision-making instrument. Since the late 19th century, the group (also known as jury, team, crowd, and swarm) has been deplored as a source of intellectual inferiority (*1*) and disastrous policy decisions (*2*) and hailed as a source of near-magical creativity (*3*) and unparalleled wisdom and forecast accuracy (*4*, *5*). Some of these attributions have proved to be unfounded. For instance, with respect to creative potential, groups that engage in brainstorming lag hopelessly behind the same number of individuals working alone (*6*). The key to benefiting from other minds is to know when to rely on the group and when to walk alone. On page 360 of this issue, Koriat (*7*) explores the value of individual confidence in group decision-making.

After a medical test, the physician tells you that the results suggest a worrying abnormality. Despite the doctor's high confidence in her conclusion, you seek a second opinion. The second physician believes that the cause is probably benign. But his level of confidence is lower than the first physician's. Whose opinion should you believe?

Koriat's analysis speaks to such dilemmas. Presenting his participants with inference tasks involving two alternatives (such as which of two countries has a larger area), he shows that members of dyads—and, by extension, larger groups—can tap into the wisdom of two heads even in the absence of social interaction by using a simple heuristic: Select the response expressed with the higher—or in the case of more than two heads, highest—degree of confidence.

This maximum-confidence slating (MCS) heuristic enables humans to benefit from the presence of two or more opinions in choice tasks. Another simple and highly adaptive combination tool in choice tasks is the majority rule, but it requires at least three opinions (*8*). In estimation tasks, no combination strategy rivals the intelligent simplicity of averaging, which exploits the benefit of error cancellation (*9*).

Why and when does the MCS heuristic work? By using the subjective confidence of each judge in the accuracy of their response, the heuristic flexibly adopts the opinion of one or the other judge. It does not bet that the same person will always be the best judge (while not precluding this possibility), but rather adaptively aligns itself with the judge who produces the most confident response in a given trial. In his first two experiments, Koriat shows that using this heuristic enables a level of inferential accuracy that is substantially higher than that achieved by the dyad's higher-performing member. Furthermore, a person who responds to the same task twice, separated by an interval and thus enabling variability (for example by forgetting), can boost accuracy by select-



The role of confidence. In "wicked" environments (**A**), in which confidence correlates positively with the majority opinion (red dots) and the majority opinion correlates negatively with the criterion (correct response), confidence is an invalid predictor of the criterion. In contrast, Koriat shows that relying on the more confident response of a virtual dyad fosters accuracy in "kind" environments (**B**), in which confidence correlates positively with the majority opinion (green dots), and the latter correlates positively with the criterion.

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ing the response in which he has higher confidence, thus exploiting the wisdom of the crowd in a single mind (*10*).

The fact that a judge's confidence can be a valid predictor of accuracy is remarkable in light of the bad reputation that subjective confidence has acquired in many areas of psychology and behavioral economics. Numerous studies (*11*) have found that people's confidence in the accuracy of their judgments or predictions is systematically greater than the judgments' actual accuracy.

However, according to proponents of an ecological approach to understanding the human mind (*12*), overconfidence does not reflect faulty cognitive software. Rather, it results from experimenters' frequent practice of sampling questions in such a way that otherwise sound knowledge results in wrong inferences. For instance, one does not need to know much about the populations of French cities to infer correctly that Paris has more residents than Toulouse: Paris is the capital of France, and in many countries the capital is the largest metropolis. Yet the "capital" cue can suggest a wrong inference. For instance, residents of Zurich outnumber those of Bern, but the latter is the Swiss capital. Many disagreements in psychology about the reality and significance of overconfidence can be traced to how experimenters select their stimuli (such as knowledge questions) (*13*).

Koriat elegantly integrates this ecological approach to confidence with research on the wisdom of the crowd. His third and fourth experiments show that when tasks are sampled such that misleading ones are overrepresented, the accuracy of the MCS heuristic falls below that of each individual. In such "wicked" environments (see the figure, panel A), betting on the more confident response ceases to be adaptive. In contrast, in "kind" environments (*14*) (panel B), the MCS heuristic tops the better individual.

So what should one make of conflicting medical opinions? That depends on whether the medical world represents a predominantly wicked or kind environment and whether you can tell one from the other, which raises two questions for future research. First, is it possible to sort environments according to whether or not shared knowledge and majority opinions are more often right than wrong? One variable that may enable such classification is the degree to which an environment involves competitive or cooperative interactions (*15*). Second, are there probabilistic cues that can help to distinguish between kind and wicked environments (or help to infer whether the experimenter selected questions to trick us)? If so, an adaptive decision-maker can strategically choose between Koriat's MCS heuristic and its opposite: Select the response expressed with the lower degree of confidence.

In the absence of such cues, and given that human communication norms (*16*) presumably give rise to common knowledge that is more likely true than not, Koriat has sound advice: Take the more confident response.

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10.1126/science.1221403

CANCER

Heterogeneity and Tumor History

What can genomic heterogeneity within a single tumor reveal about the tumor's evolution and its diagnosis?

Darryl Shibata

All cells are almost perfect copies of prior cells. Imperfect DNA replication creates random variation, which is the substrate for evolution. Such differences may be small [normally about one new mutation per human cell division (*1*)], but the accumulation of mutations over time can eventually transform a single cell. Progeny of this first transformed cell expand by bifurcating branching cell division (see the figure) to form visible billion-cell clonal tumor populations. Each one of these cancer cells is an almost perfect copy of the first transformed cell. Given this scenario, different genetic alterations in different parts of the same cancer should be found in most tumors. Such intratumor heterogeneity has been found in many cancers, but its true extent is becoming much more evident with the unprecedented ability to sequence genome-wide many times (deep sequencing).

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Intratumor heterogeneity has been found whenever deep sequencing has been appropriately applied to different parts of the same cancer for the colon, pancreas, breast, and blood (*2*–*5*). The recent study by Gerlinger *et al*. (*6*) highlights this phenomenon, as over half the mutations in multiple different parts of the same advanced renal cell carcinoma (primary tumor and its metastases) were different. Topographical differences in chromosome copy-number variations and gene expression signatures were also readily found, indicating that with high-resolution methods, intratumor heterogeneity is present wherever one looks.

One conclusion drawn from this baffling intratumor heterogeneity is that applying molecular signatures of prognosis or therapy to individual patients will be extremely difficult because the "answer" will vary depending on what part of the tumor is sampled (*7*). Analyzing more biopsies and sequencing even deeper are likely to reveal even more abnormalities and heterogeneity. Because all genomes are almost perfect copies of prior genomes, potentially the history of a tumor is encoded by its heterogeneity. With a simple molecular clock hypothesis (the number of differences between two genomes increases with the number of divisions since a common ancestor), the heterogeneity within and between different parts of the same tumor can indicate how long ago transformation occurred and how cancer cells spread and migrate during progression. Heterogeneity

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