Viewpoint

Entangled in a dating game

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Entanglement, a crucial resource in quantum information theory, can also improve communication over a classical channel.

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A Viewpoint on:
Entanglement-Enhanced Classical Communication Over a Noisy Classical Channel
R. Prevedel, Y. Lu, W. Matthews, R. Kaltenbaek, and K. J. Resch

In the 90s, when quantum information was a young field, Charles Bennett and others found that entanglement—a property of quantum mechanics that links different quantum objects so that they cannot, in effect, behave independently—can assist in teleporting quantum bits [1] and in increasing communication rates over both noiseless [2] and noisy quantum channels [3]. However, they also suggested that entanglement would not be particularly helpful [3] when it came to enhancing the capacity of a classical channel. Given this, it is perhaps surprising that Robert Prevedel and his coauthors at the University of Waterloo, Canada, in their paper in Physical Review Letters, show that entanglement can be helpful in a noisy classical channel [4]. They observe this effect because their setup differs from that considered by Bennett and others. Rather than allowing many uses of the classical channel and demanding that communication error rates become negligible in the limit of many uses (as is conventional in quantum information theory), they allow just one use of the classical channel and consider maximizing the chances for a receiver to guess a sender’s transmitted message. The upshot is that entanglement can improve performance here.

Perhaps the best way to explain how entanglement plays a role is with a dating game that we’ll call “Guess That Button.” The game has two contestants, Alice and Bob, who sit in different rooms. The game show host gives Alice the game board (see Fig. 1), and Alice randomly pushes one of the four buttons on the board. Three edges (green, blue, or red) touch the button that Alice pushes. The host then takes the board from Alice, goes to Bob’s room, hands him the board, and one of these three edges randomly lights up. It is Bob’s task to “guess that button.” If he does so correctly, he wins a free dinner with Alice at the nicest sushi restaurant in town.

Bob is a bit helpless without more information. Two buttons touch each edge, and he really has to guess randomly which button Alice pushed. His chances of winning are 50/50, not great odds for a dinner date. It turns out that Alice kind of likes Bob (and she really likes sushi). She realizes that his chances of winning are slim, so she asks the game show host if he’ll allow a strategy with higher chances for a win. The game show host agrees and suggests that Alice randomly pushes either
a white or a grey button. He says now that it is Bob’s
task to guess the color of the button that she pushes. Al-
ice and Bob agree beforehand (a “code” in the parlance
of communication theory) that she’ll randomly pick just
one of the buttons on the left.

Bob’s chance to “guess that button” increase sign-
ificantly with this modified strategy. Suppose Alice
pushes the white button on the left. In this case, at
random, either the blue, red, or green edge touching it
lights up. If the green or red edge lights up, then 2/3
of the time Bob knows Alice pushed the white button
because they agreed she wouldn’t push a button on the
right. If the blue edge lights up, then 1/3 of the time Bob
has to guess randomly which button Alice pushed. So
the chances of Bob guessing correctly when Alice pushes
the white button on the left are 2/3 + 1/3 * 1/2 = 5/6.
Since the game board is symmetric, the chances of win-
ning are the same if Alice pushes the grey button. So, the
overall chance for them to win a free sushi dinner is 5/6.
It turns out that this is the best strategy they could use
while still keeping the game interesting, that is, a game
of chance.

Now enter entanglement. Suppose the host allows
Alice and Bob to share two entangled particles before
the game begins. Having access to good entanglement
increases their chances of winning that dinner if they
employ the following strategy: Alice first randomly de-
cides whether she’ll push one of the two white buttons
on the top or one of the two grey buttons on the bottom,
and she measures her half of the entangled state in a
particular way depending on this choice. Each measure-
ment has two possible outcomes. After making this “top
or bottom” choice and performing the measurement,
she then pushes the button on the left or on the right,
depending on the outcome of the measurement. The
game show host gives the board to Bob, and one of the
green, blue, or red edges touching the button that Alice
pushed, randomly lights up. The green edge lights up
1/3 of the time, and if it does, Bob can determine with
certainty whether Alice pushed a white or grey button.
If the red or blue edge lights up, Bob employs a differ-
ent strategy. He measures his half of the shared entan-
glement in a particular way, depending on certain infor-
mation that he would like to learn. With an 85% chance,
he can correctly determine either the red or blue edge
that touches the button Alice pushed. This is due to the
strong correlations in entanglement—classical corre-
lations would only give him a 75% chance of learning this
information correctly. So, if the blue edge lights up, it is
better for him to determine the red edge, and he chooses
the measurement that will give him this information
correctly 85% of the time. It is better to determine red
because he already knows the blue edge, and if he de-
termines the red edge correctly, he can figure out exactly
which button Alice pushed, and thus whether it was
white or grey. Similarly, if the red edge lights up, he can
correctly determine 85% of the time that the blue edge
touches the button Alice pushed, and then make a good
guess at which button Alice pushed. Adding things up,
he’ll guess correctly the color of the button Alice pushed
1/3 of the time (the chance that the lit edge is green),
and he’ll guess correctly 2/3 * (85%) = 57% of the time
when the lit edge is red or blue. Thus the total chance of
guessing the color of the button Alice pushed is about
1/3 + 57% ≈ 90%. If they only share classical corre-
lations, the total chance is 1/3 + 2/3 * (75%) = 5/6,
which is no better than the classical strategy in the pre-
vious paragraph. Thus entanglement gives a significant
7% boost to their chances of winning a sushi dinner.

To verify that these results aren’t just magic, Prevedel
et al. performed an experimental implementation of
the “Guess That Button” game on an optics bench in
their quantum optics lab. In place of real contestants
in a game show, they simulated the game using polar-
ization entangled photons between two measurement
devices, Alice and Bob, and an electronic logic circuit
connected to a random number generator that imple-
mented the noisy channel (or, in our analogy, selected
randomly which edge would light up). The polariza-
tion entanglement was generated using a process called
down-conversion, in which a high-energy photon can
break into two lower energy photons. One of the pho-
tons in the pair was sent to Alice, the other to Bob. In
their realization, Alice would randomly choose which
of the buttons to push by which way her photon hap-
pened to go out of a beam-splitter and the result of a
photon counting measurement. Bob’s local decoding ac-
tion was implemented using fast optical switches and
measurement. The experiment was conducted for about
10 minutes, and, using data from photodetectors, they
determined that Alice and Bob were winning about 89% of
the time when Alice and Bob had access to shared
entanglement. This success rate far exceeds what one
would expect from the theoretical success probability
for a classical strategy, and it is just under the theoreti-
cal success probability for the quantum strategy (likely
due to slight imperfections in the entangled state).

References

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About the Author

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Mark M. Wilde received his B.S. degree in computer engineering from Texas A&M University in 2002, his M.S. degree in electrical engineering from Tulane University in 2004, and his Ph.D. degree in electrical engineering from the University of Southern California in 2008. Currently, he is a Postdoctoral Fellow at the School of Computer Science, McGill University. He has published about 40 articles and preprints in the area of quantum information processing. His current research interests are in quantum error correction and quantum Shannon theory.