

# A Distributed Coordination Problem

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Keith Marzullo

<https://www.youtube.com/watch?app=desktop&v=IP-rGJKSZ3s>

It is impossible for two distributed processes communicating  
via an unreliable message system to reach consensus

# Two Generals' Problem

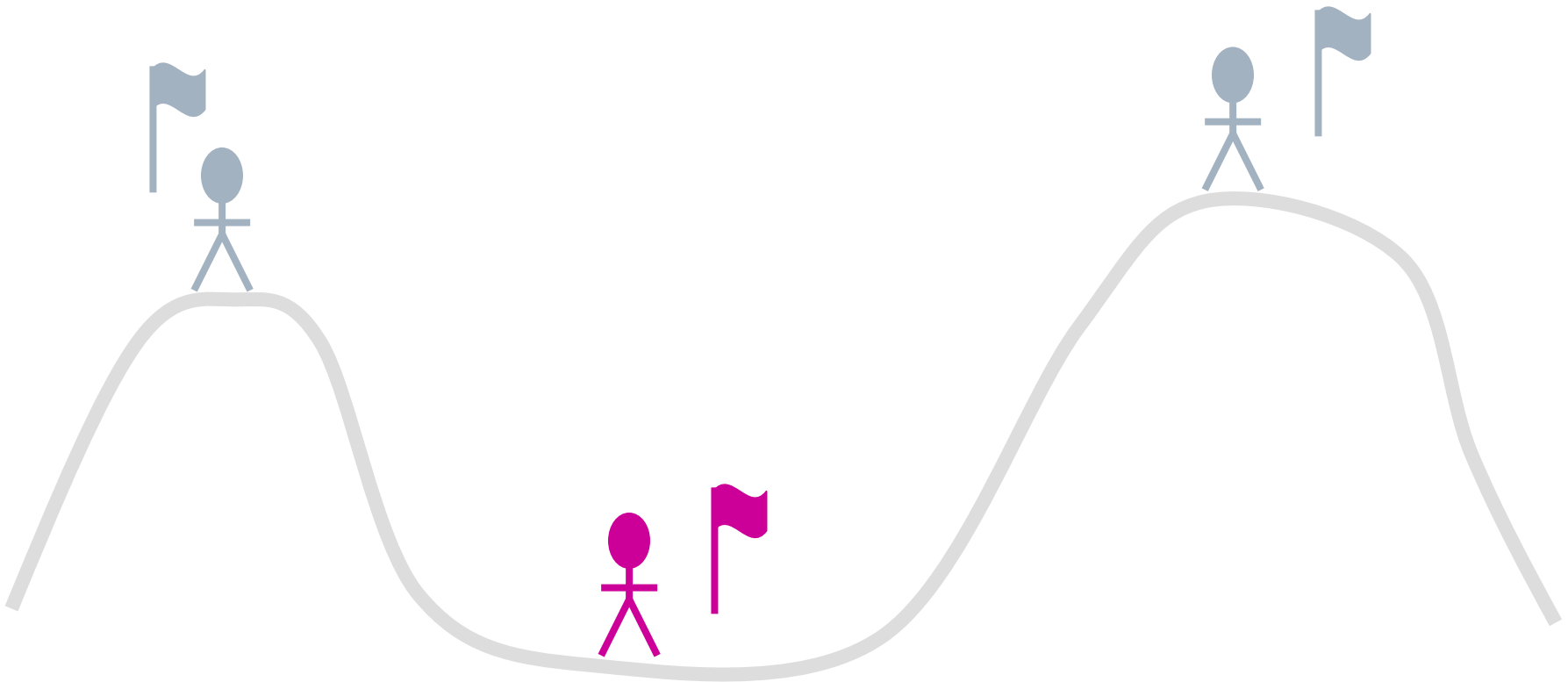
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Two armies are camped on separate hills surrounding a valley in which the enemy army is encamped.

The enemy can vanquish each general separately, but if both generals attack at the same time, they can vanquish the enemy.

# Two Generals' Problem

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*due to Jim Gray, 1978*

# Two Generals' Problem

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The two generals must communicate with each other to agree upon whether or not to attack at dawn.

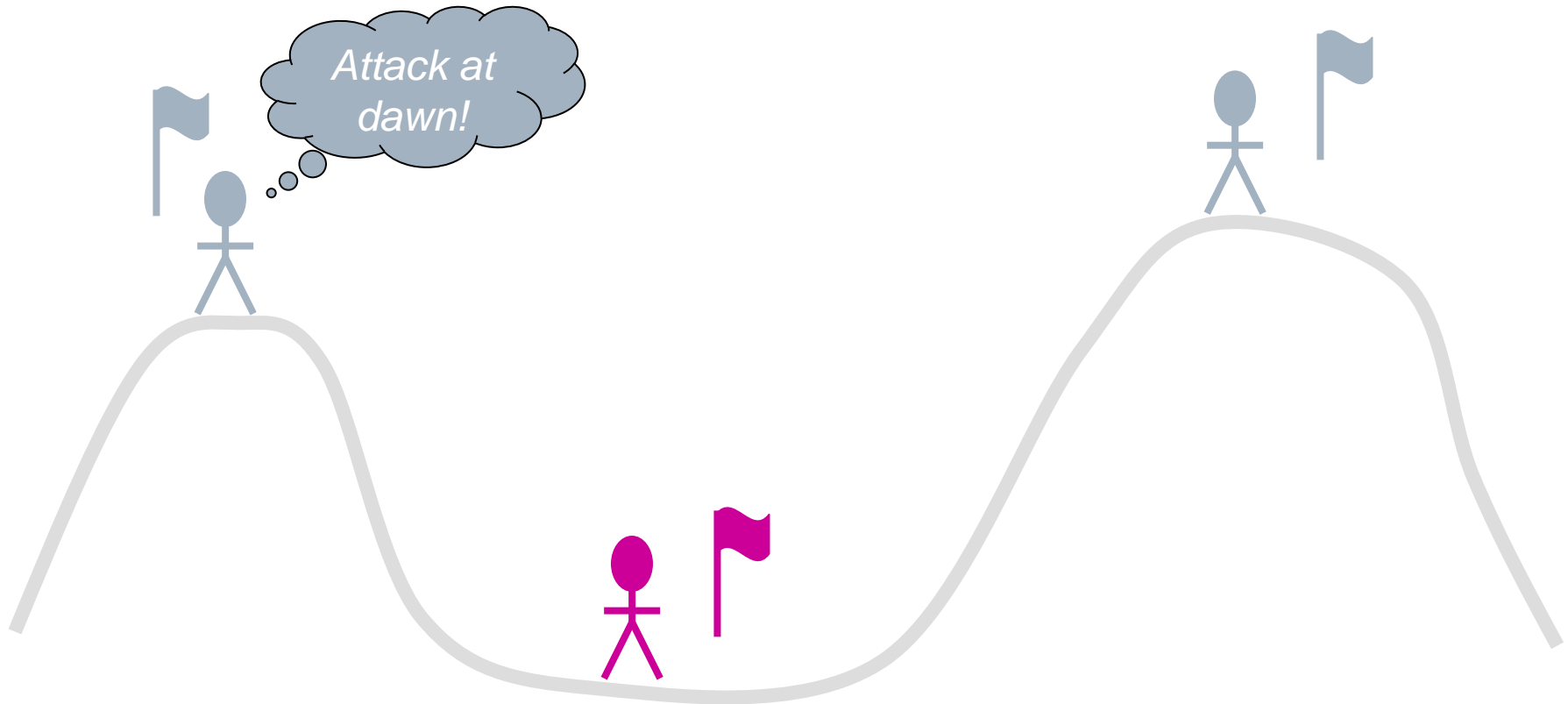
Each general must know that the other general knows that they have agreed to the attack plan.

There should be a shared certainty for both generals to attack.

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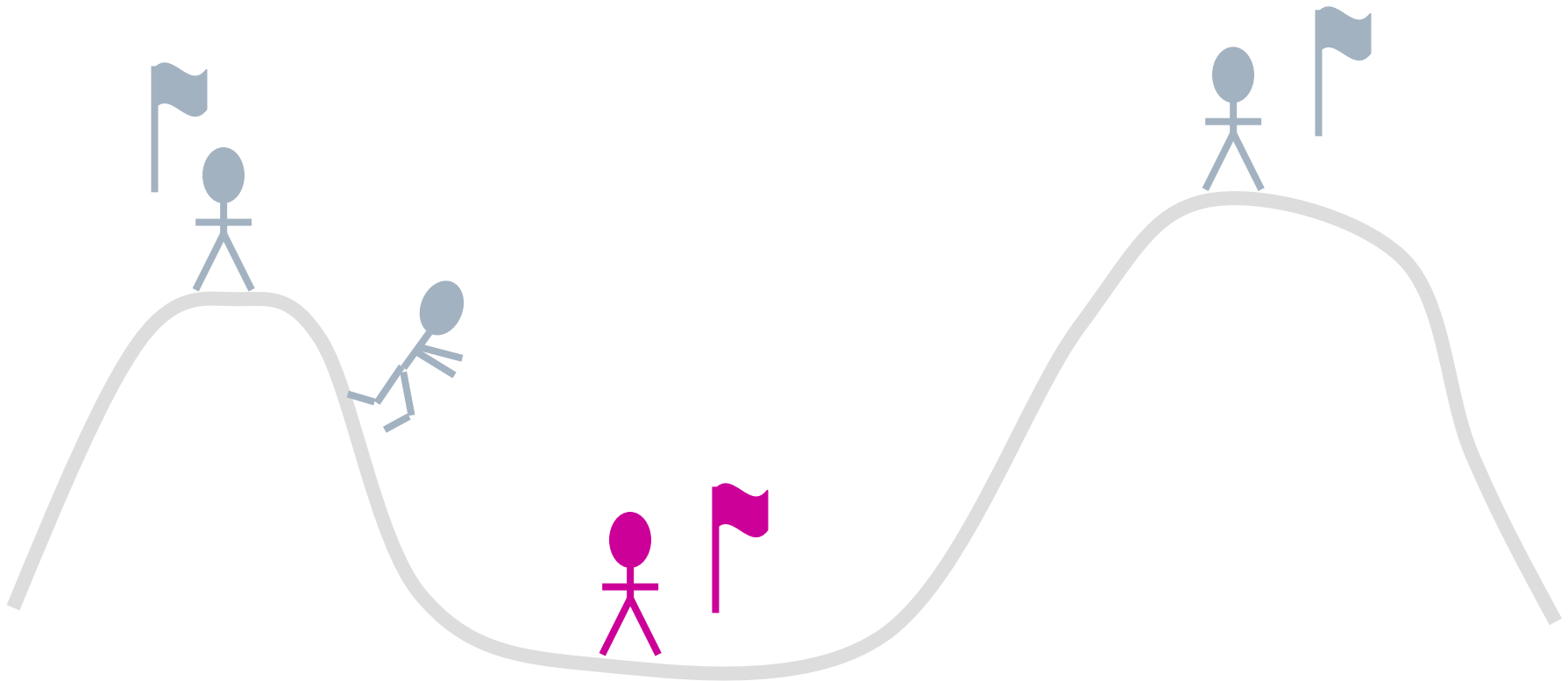
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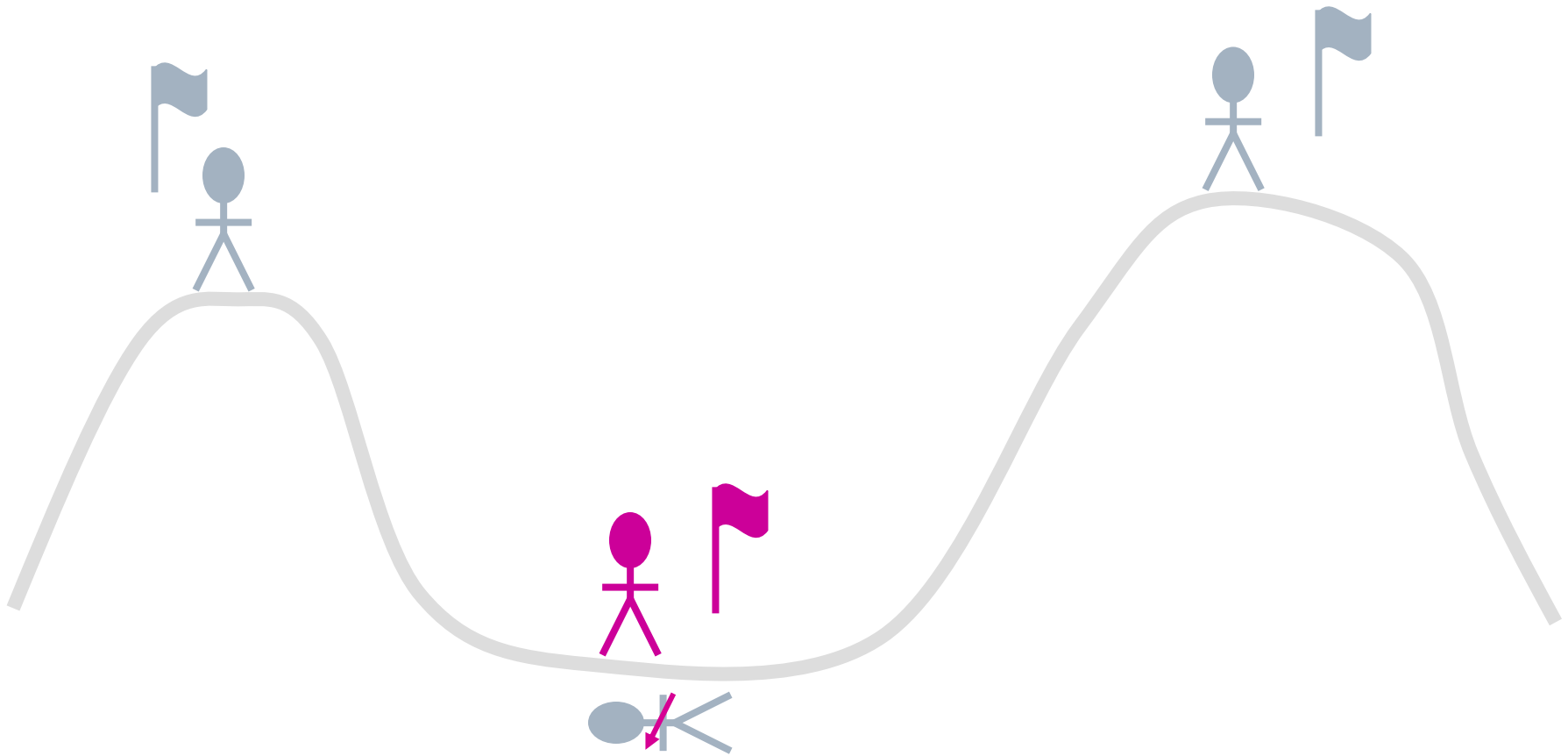
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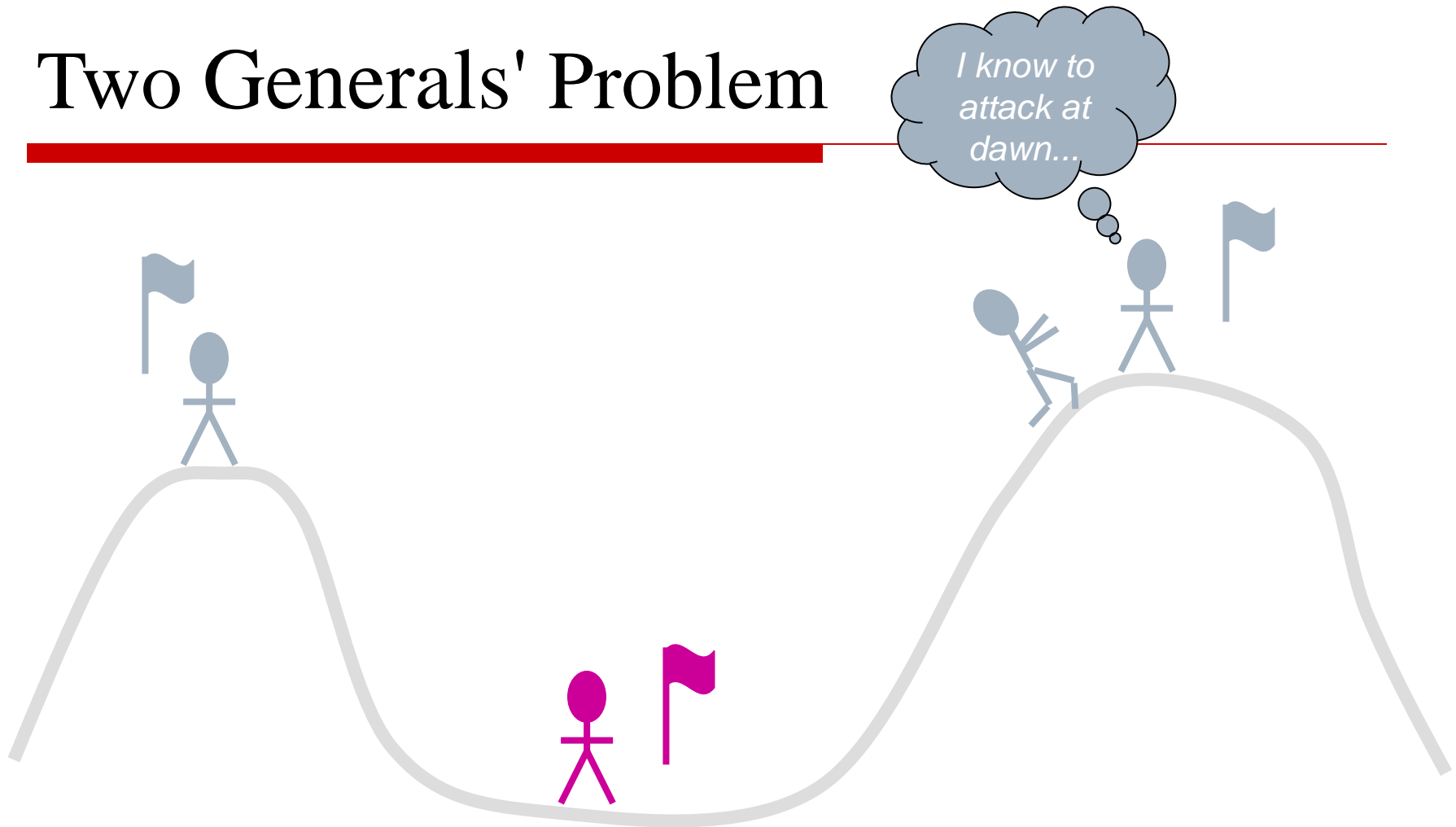
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# Two Generals' Problem

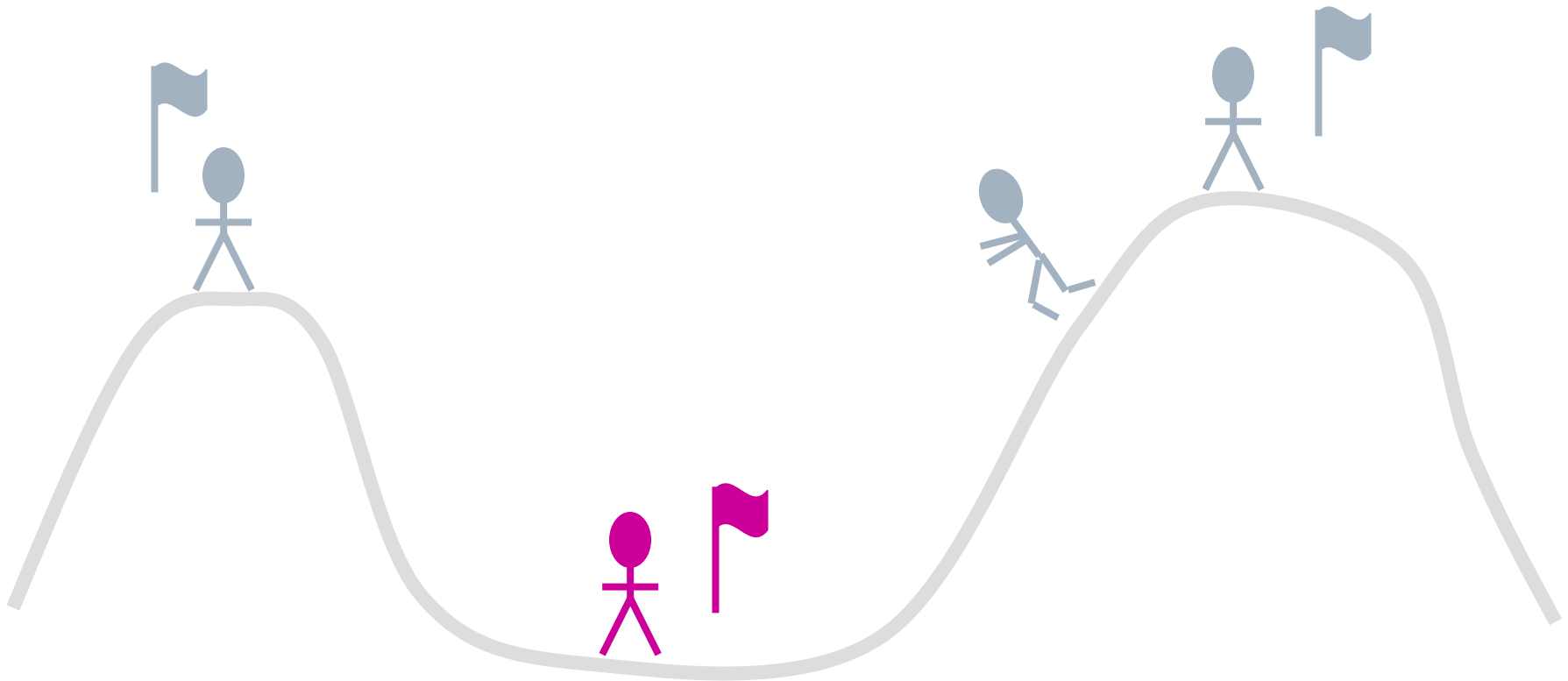
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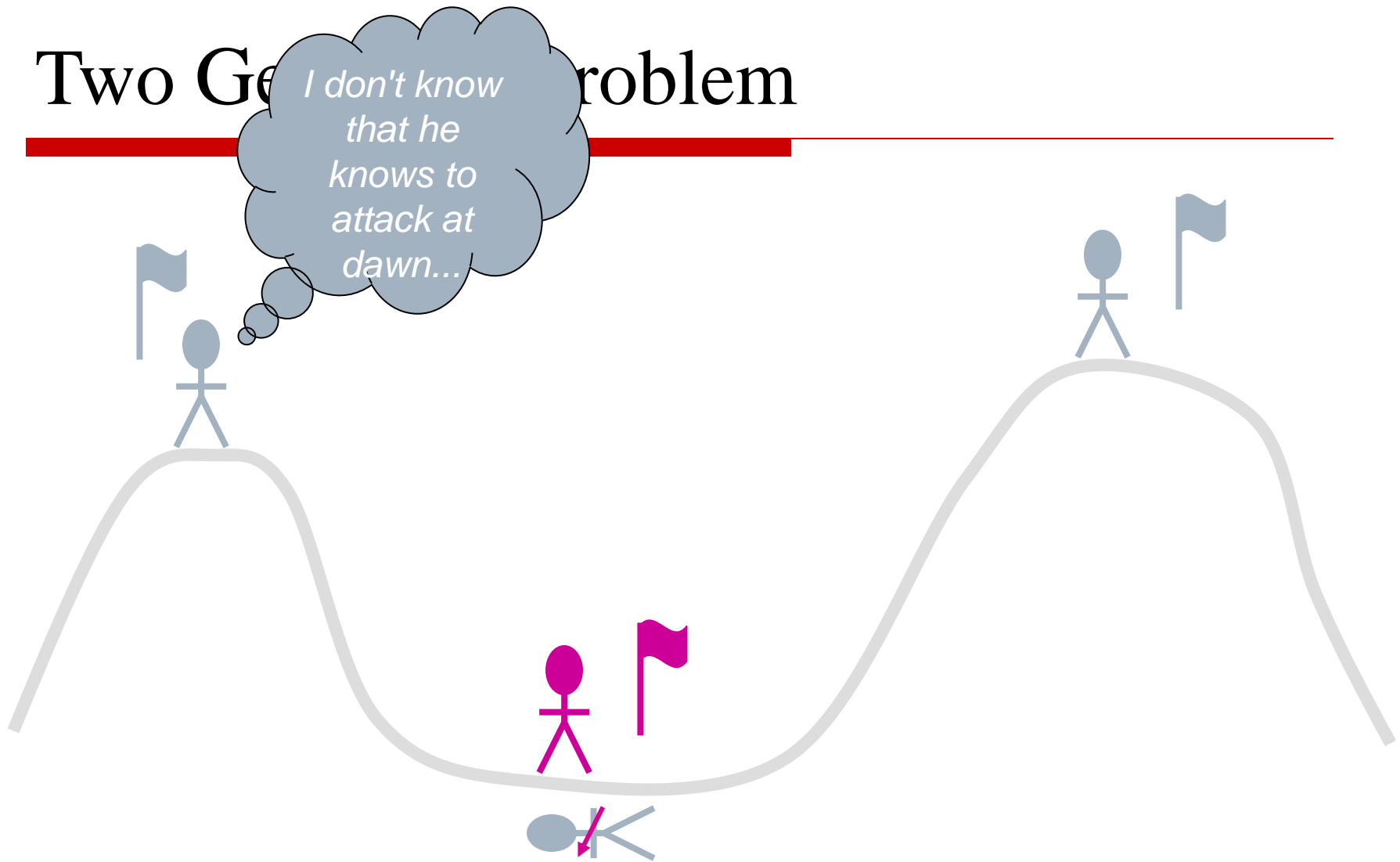
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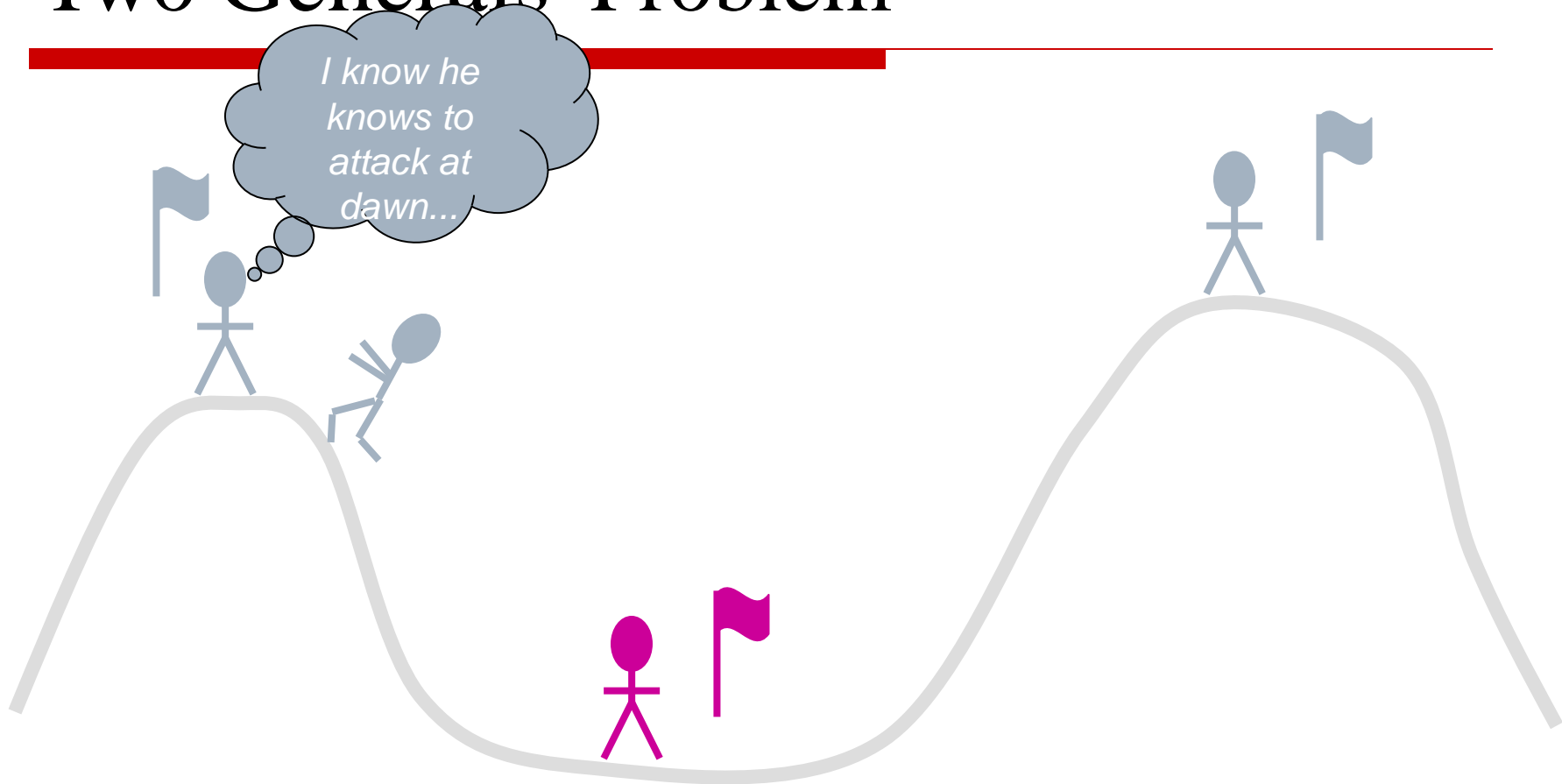
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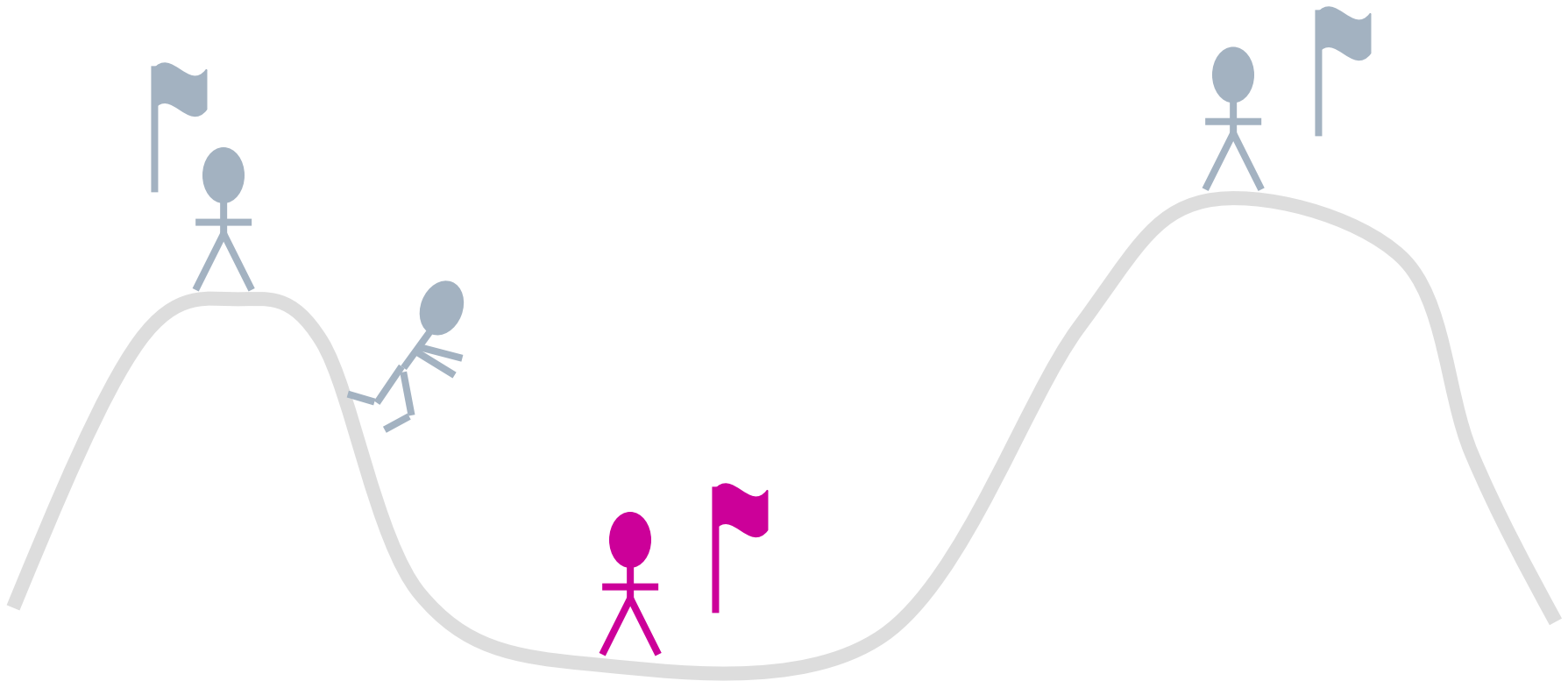
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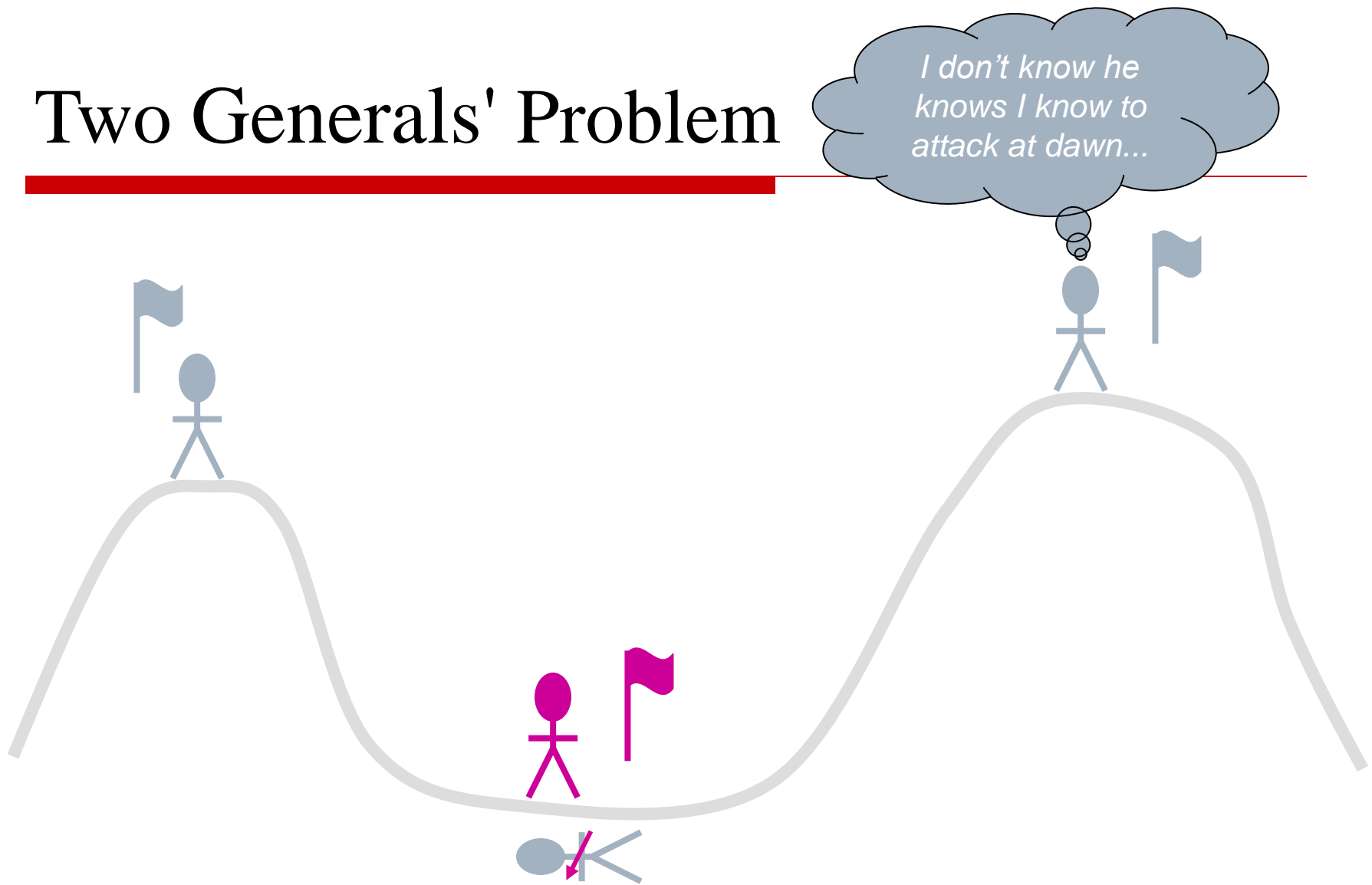
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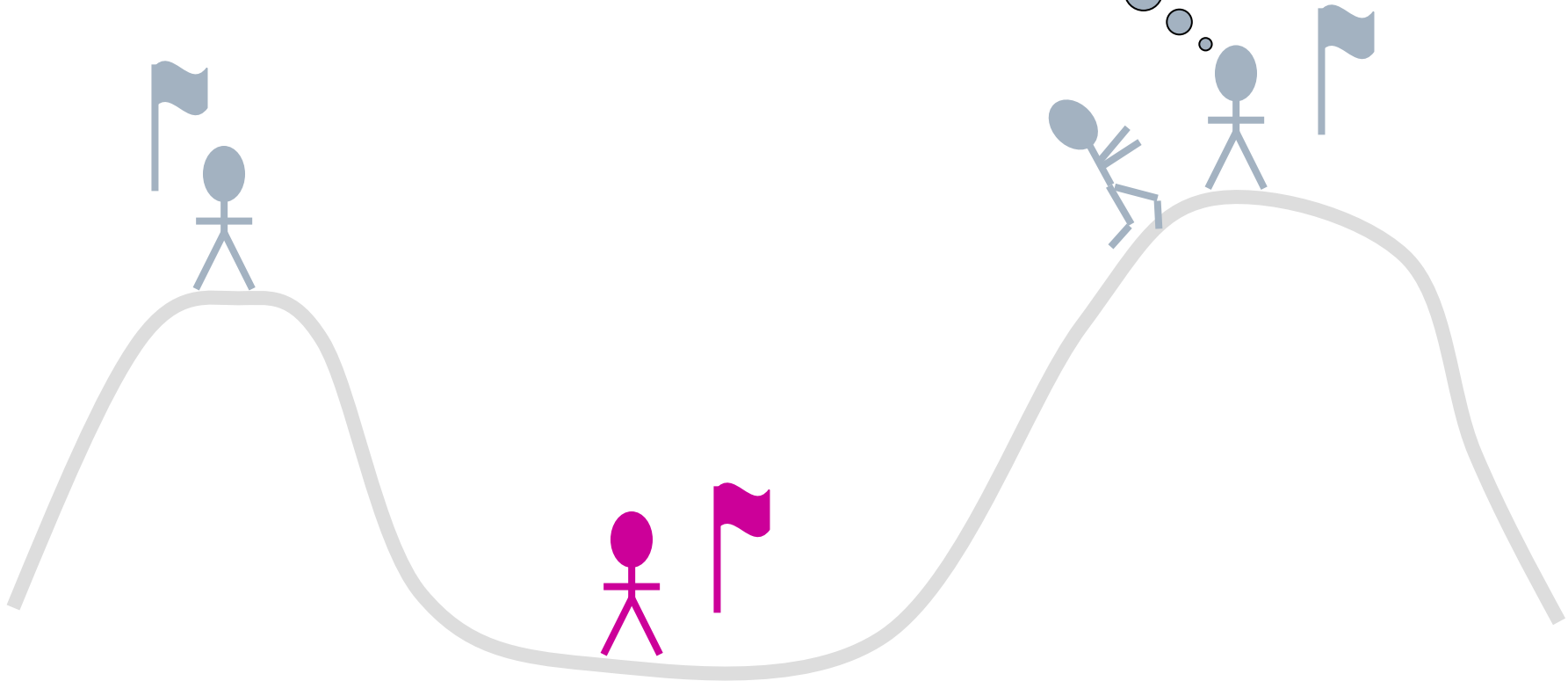
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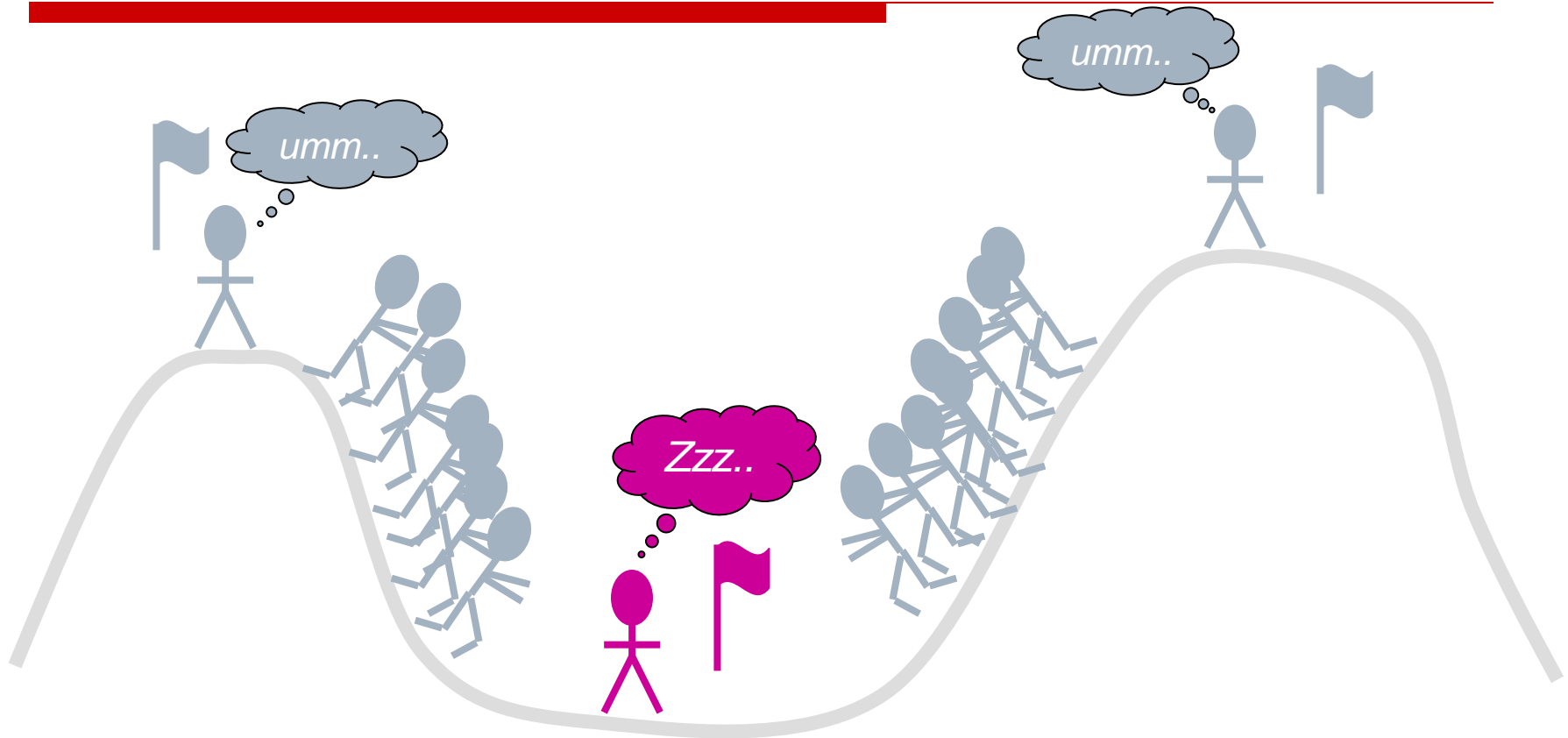
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*I know he  
knows that I  
know to attack  
at dawn...*



# Two Generals' Problem

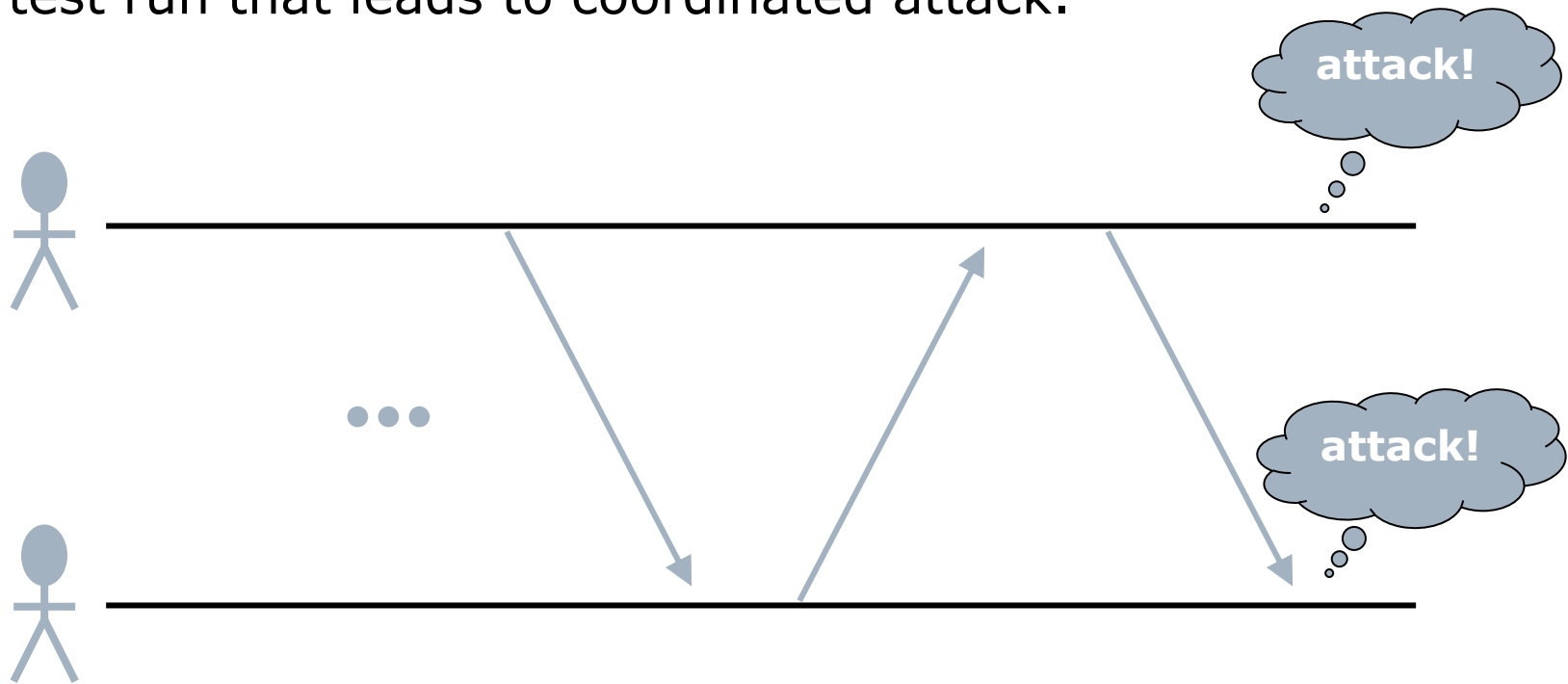
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# No Finite Protocol: Proof

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Assume a protocol  $P$  exists and consider the shortest run that leads to coordinated attack.





# No Finite Protocol: Proof

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- Suppose the last messenger in  $P$  gets lost.

Country	Year	Value
Algeria	2010	0.00
Algeria	2011	0.00
Algeria	2012	0.00
Algeria	2013	0.00
Algeria	2014	0.00
Algeria	2015	0.00
Algeria	2016	0.00
Algeria	2017	0.00
Algeria	2018	0.00
Algeria	2019	0.00
Algeria	2020	0.00
Algeria	2021	0.00
Algeria	2022	0.00
Algeria	2023	0.00
Algeria	2024	0.00
Algeria	2025	0.00
Algeria	2026	0.00
Algeria	2027	0.00
Algeria	2028	0.00
Algeria	2029	0.00
Algeria	2030	0.00
Algeria	2031	0.00
Algeria	2032	0.00
Algeria	2033	0.00
Algeria	2034	0.00
Algeria	2035	0.00
Algeria	2036	0.00
Algeria	2037	0.00
Algeria	2038	0.00
Algeria	2039	0.00
Algeria	2040	0.00
Algeria	2041	0.00
Algeria	2042	0.00
Algeria	2043	0.00
Algeria	2044	0.00
Algeria	2045	0.00
Algeria	2046	0.00
Algeria	2047	0.00
Algeria	2048	0.00
Algeria	2049	0.00
Algeria	2050	0.00
Algeria	2051	0.00
Algeria	2052	0.00
Algeria	2053	0.00
Algeria	2054	0.00
Algeria	2055	0.00
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Algeria	2063	0.00
Algeria	2064	0.00
Algeria	2065	0.00
Algeria	2066	0.00
Algeria	2067	0.00
Algeria	2068	0.00
Algeria	2069	0.00
Algeria	2070	0.00
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Algeria	2079	0.00
Algeria	2080	0.00
Algeria	2081	0.00
Algeria	2082	0.00
Algeria	2083	0.00
Algeria	2084	0.00
Algeria	2085	0.00
Algeria	2086	0.00
Algeria	2087	0.00
Algeria	2088	0.00
Algeria	2089	0.00
Algeria	2090	0.00
Algeria	2091	0.00
Algeria	2092	0.00
Algeria	2093	0.00
Algeria	2094	0.00
Algeria	2095	0.00
Algeria	2096	0.00
Algeria	2097	0.00
Algeria	2098	0.00
Algeria	2099	0.00
Algeria	2100	0.00
Algeria	2101	0.00
Algeria	2102	0.00
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Algeria	2109	0.00
Algeria	2110	0.00
Algeria	2111	0.00
Algeria	2112	0.00
Algeria	2113	0.00
Algeria	2114	0.00
Algeria	2115	0.00
Algeria	2116	0.00
Algeria	2117	0.00
Algeria	2118	0.00
Algeria	2119	0.00
Algeria	2120	0.00
Algeria	2121	0.00
Algeria	2122	

# No Finite Protocol: Proof

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- Then either this messenger is useless or one of the generals doesn't get a needed message.
- By the minimality of  $P$ , the last message is not useless so one of the generals doesn't march if the last message is lost.
- This contradiction proves that no such protocol  $P$  exists.

# No Finite Protocol: Proof

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Indistinguishability scenario



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Last message needed



# Unsolvable Problem

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In any distributed protocol, the sender of the last message can't tell whether it arrived.

That would require another message.

If communication reliability is any less than 100%, a consensus between two entities in a distributed network is impossible.

# Unsolvable Problem

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“No amount of user protocol can solve the problem in a manner to dissipate the anxiety of both parties as to the outcome of a transaction.”

Two groups of gangsters need to coordinate by sending messages that may be lost.

Akkoyunlu E.A., Ekanadham K., and Huber R.V. (1975)

Some constraints and tradeoffs in the design of network communications.

Proc. 5th ACM Symposium on Operating Systems Principles (SOSP), ACM Press, pp. 67-74.

# Two Insecure Lovers

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- Alice and Bob want to schedule a meeting.
- If both attend, they win, but if only one attends, defeat and humiliation is felt.
- As a result, neither will show up without a guarantee that the other will show up at the same time.

# Two Insecure Lovers

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- Communication is by SMS only.
- Normally, it takes a message one hour to arrive.
- However, it is possible that it gets lost.



# Two Insecure Lovers

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- Fortunately, on this particular night, all the messages arrive safely.
- How long will it take Alice and Bob to coordinate their meeting?

# Two Insecure Lovers

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- Alice initiates the communication at noon.
- Bob receives a message at 1:00 from Alice saying “meet at midnight”. Should Bob show up?

# Two Insecure Lovers

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- Although her message was in fact delivered, Alice does not know. She therefore considers it possible that Bob did not receive the message.
- Hence Alice cannot decide to show up, given her current state of knowledge.
- Knowing this, Bob will not show up based solely on Alice's message.

# Two Insecure Lovers

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- Naturally, Bob reacts by sending an acknowledgment back to Alice, which arrives at 2:00.
- Will Alice plan to show up?
- Unfortunately, Alice's predicament is similar to Bob's predicament at 1:00, she cannot yet decide to show up.

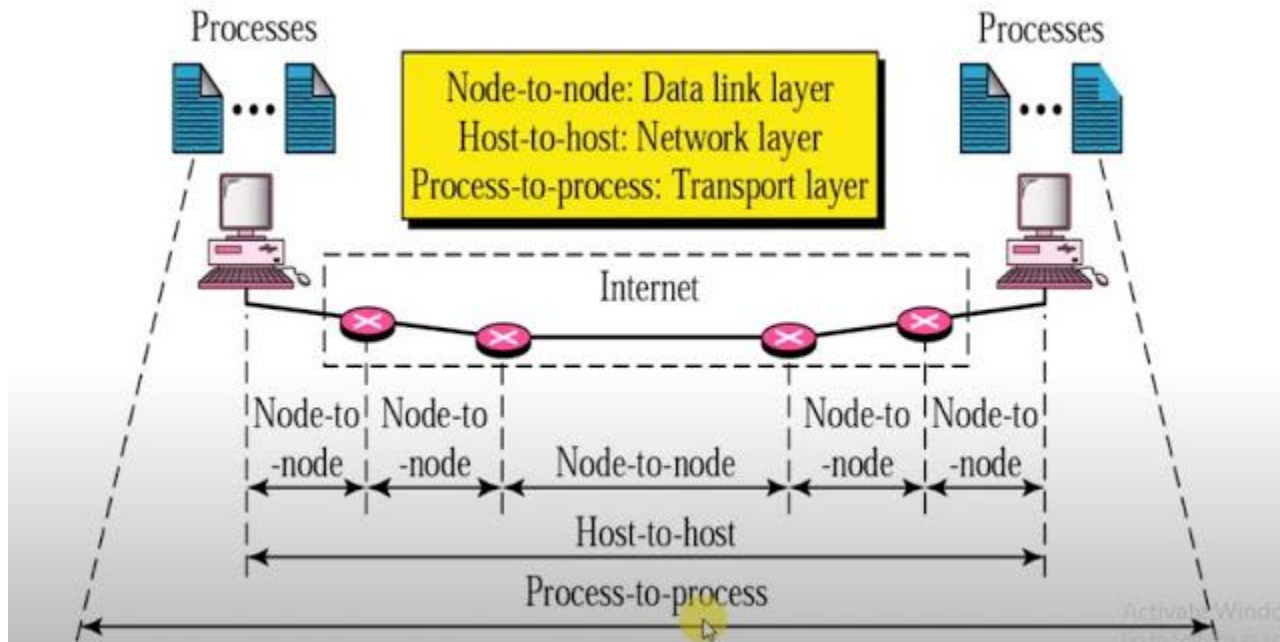
# Two Insecure Lovers

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- No number of successfully delivered acknowledgments will be enough to ensure that show up is safe!
- The key insight is that the difficulty is not caused by what actually happens (all messages actually arrive) but by the **uncertainty** regarding what might have happened.

# Two Generals Problem in TCP

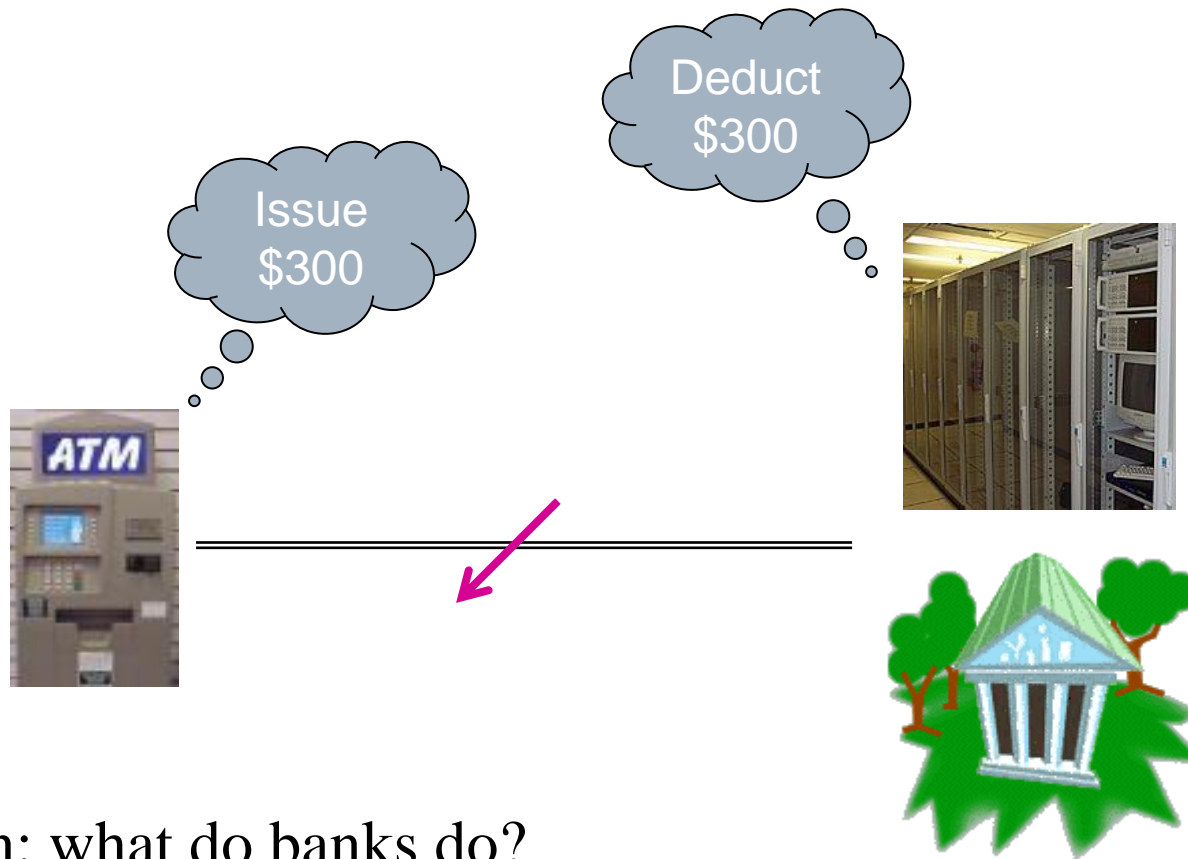
## Three-way handshakes



<https://techiechtutorials.blogspot.com/2020/02/two-army-problem-in-computer-network.html>

# Two Generals in Practice

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Question: what do banks do?