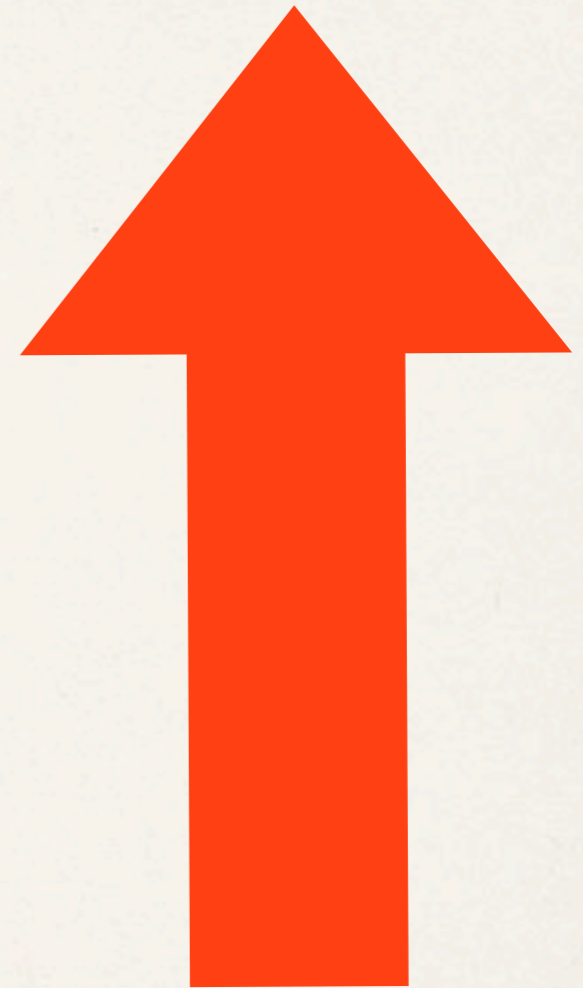


Improving communication with entanglement

Giannicola Scarpa



Improving communication with entanglement



Improving communication with entanglement

Improving communication with entanglement

- ✦ Quantum state: d -dimensional vector

Improving communication with entanglement

- ❖ Quantum state: d -dimensional vector
- ❖ Shared state can be *entangled*
(quantum correlation)

Improving communication with entanglement

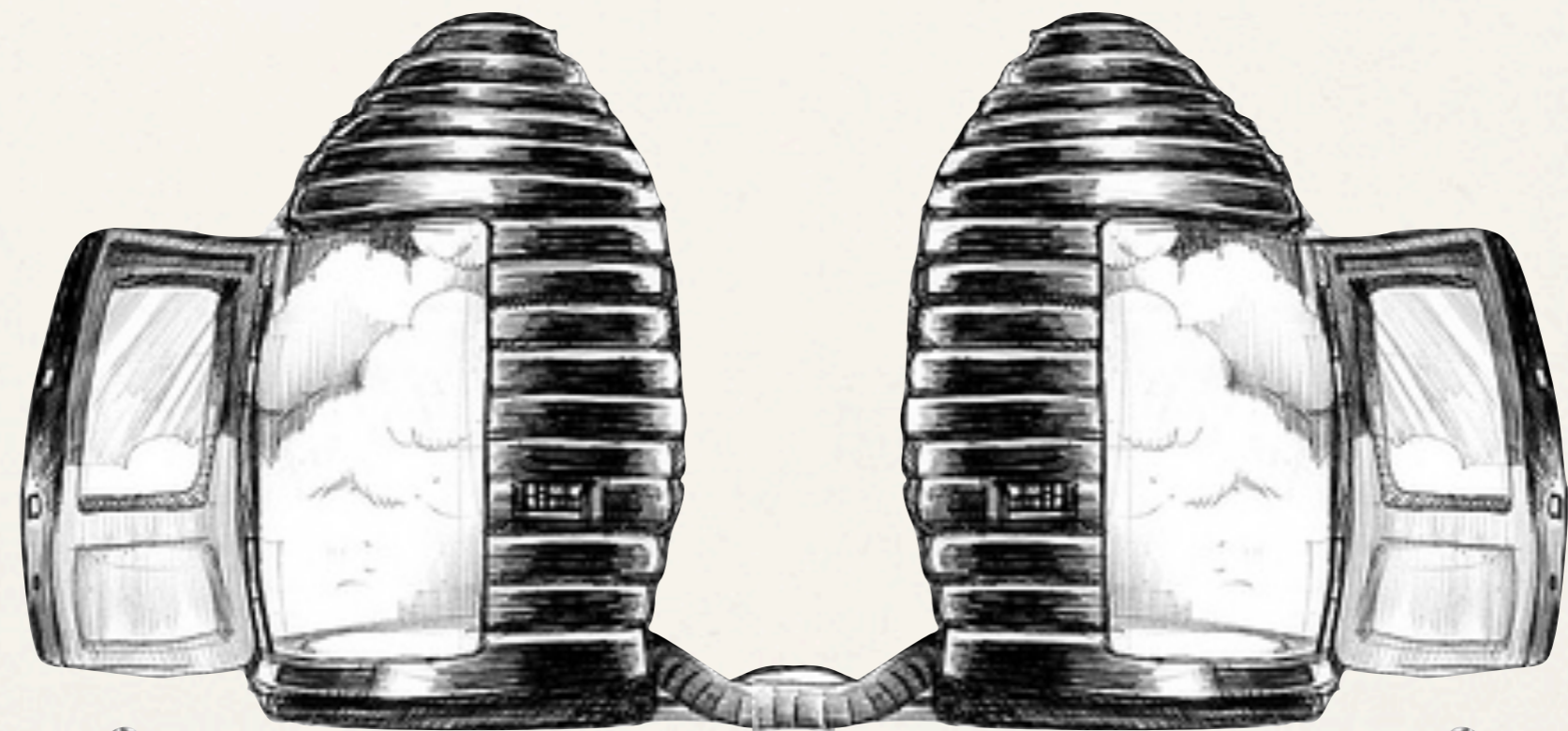
- ❖ Quantum state: d -dimensional vector
- ❖ Shared state can be *entangled*
(quantum correlation)
- ❖ Use entanglement as a resource for...

Improving communication with entanglement

(Quantum) TELEPORTATION!



Improving communication with entanglement



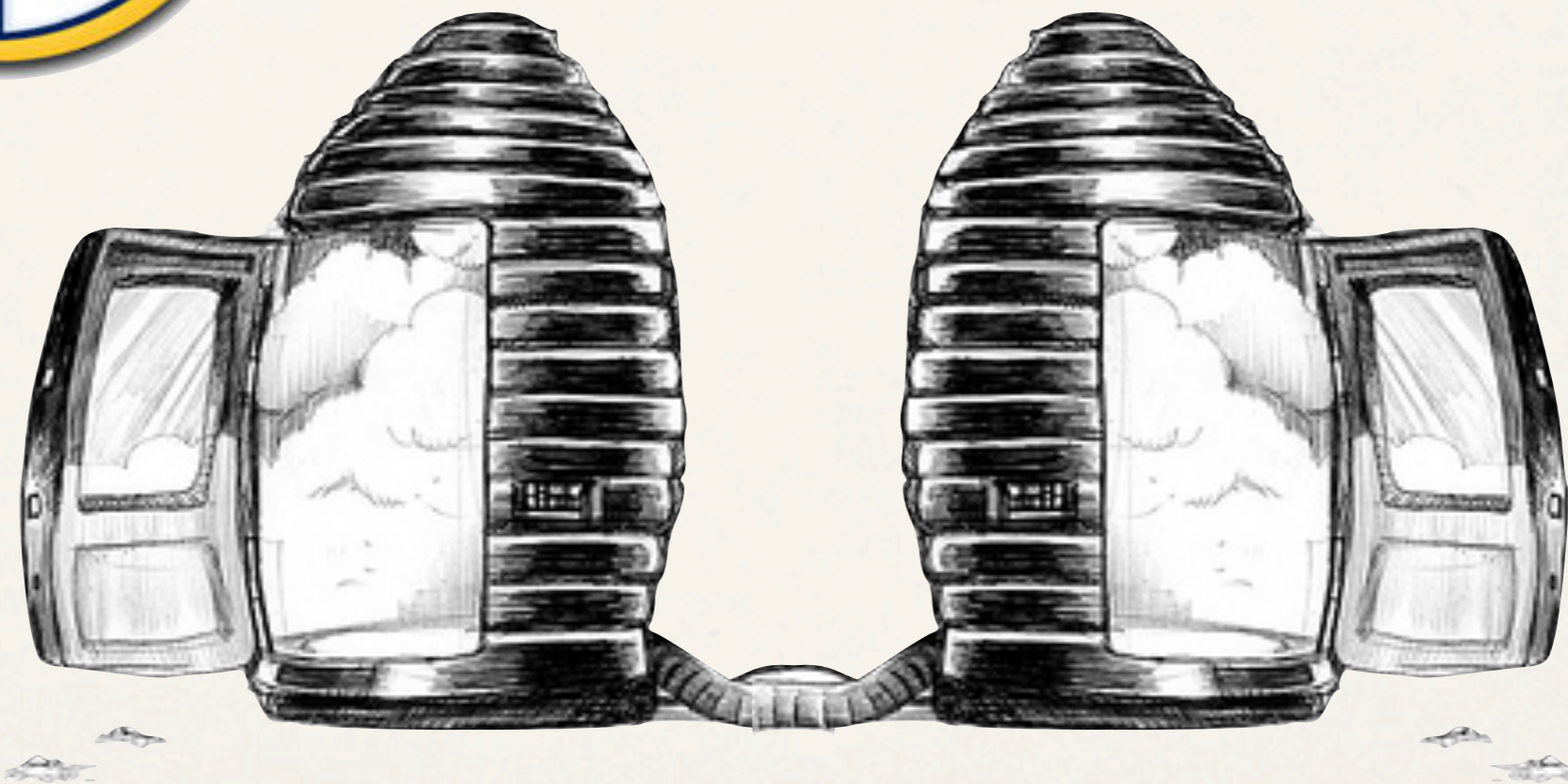
Alice

Bob

Improving communication with entanglement



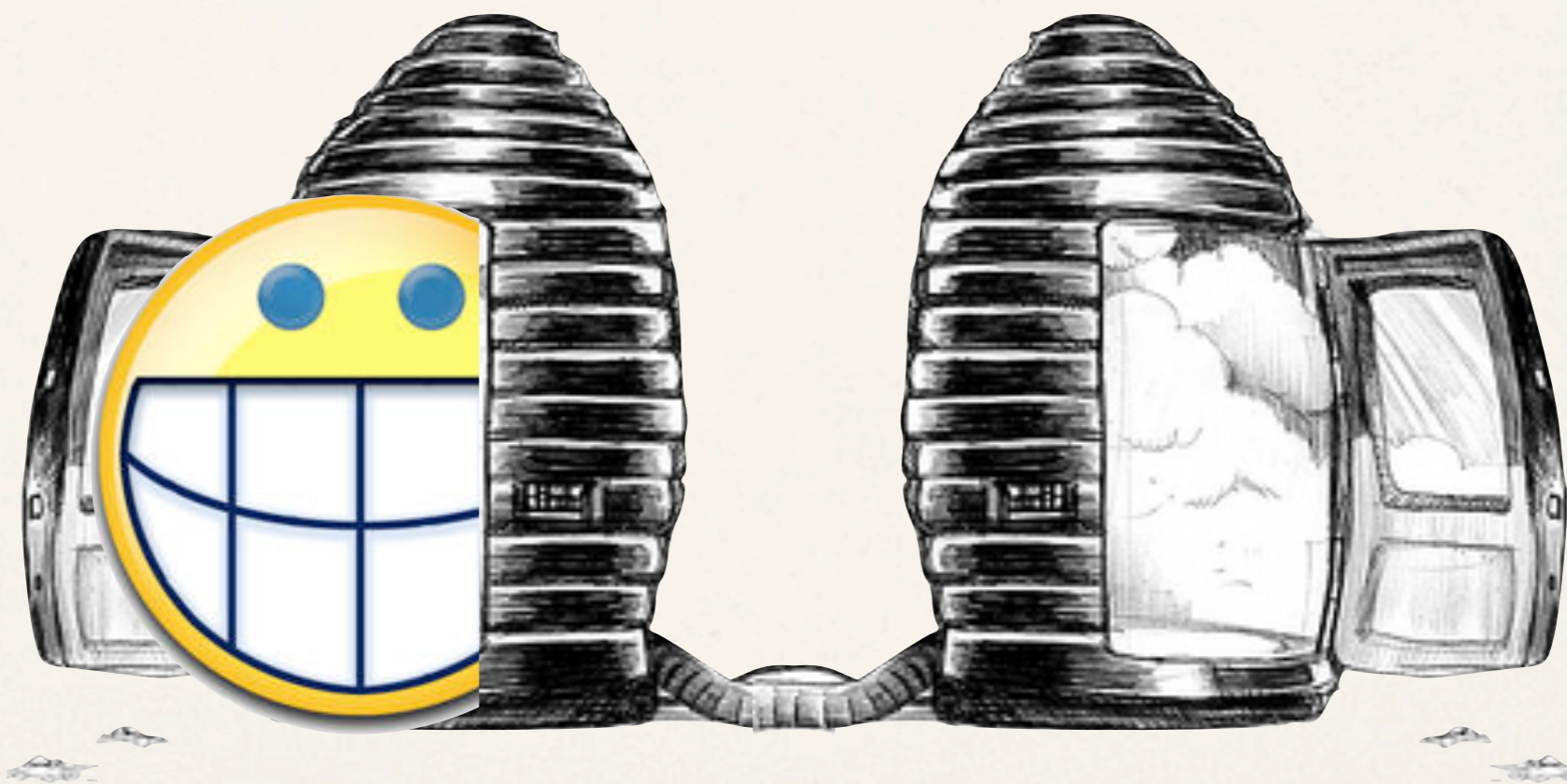
Hi, I am
d-dimensional



Alice

Bob

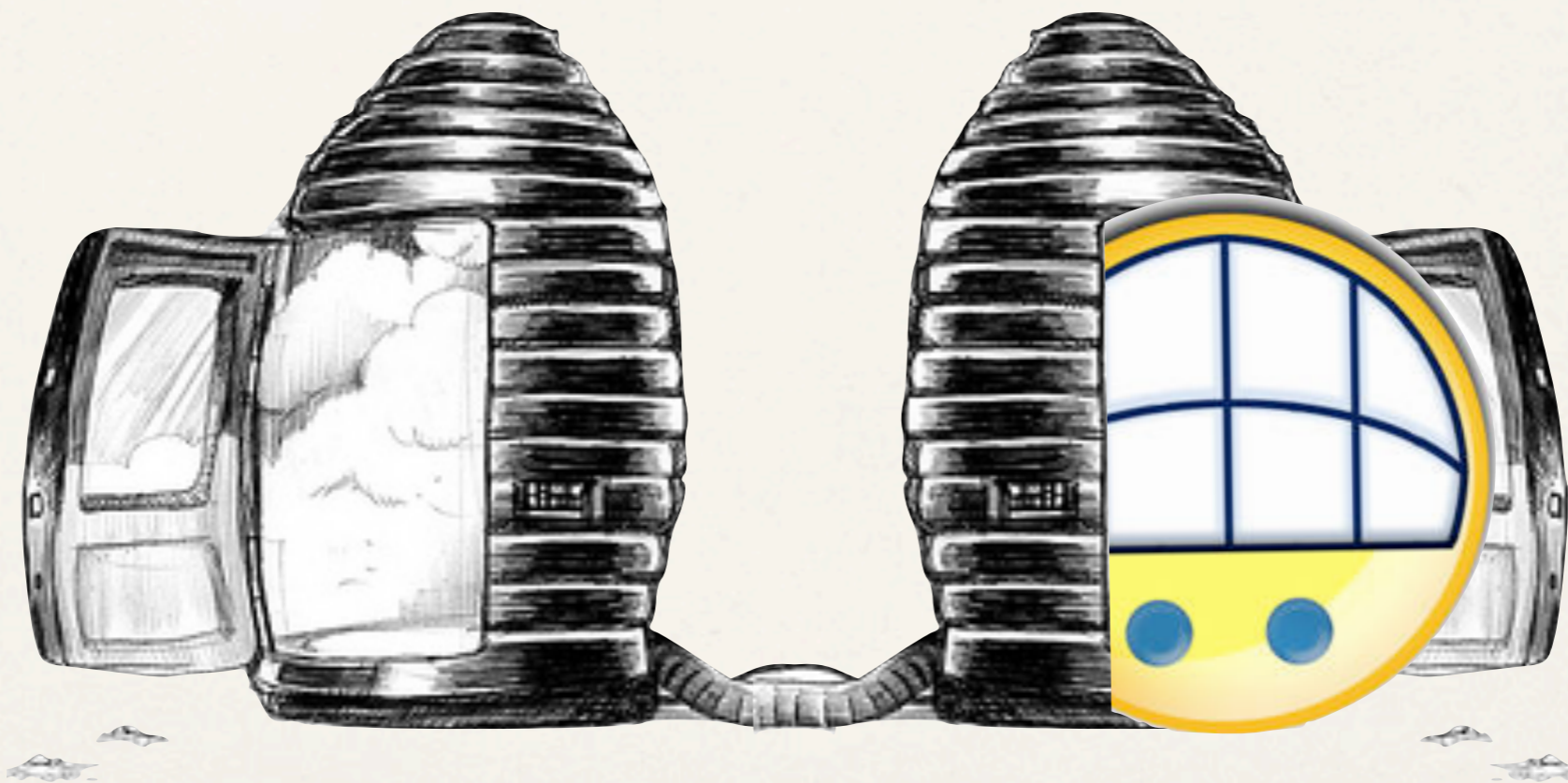
Improving communication with entanglement



Alice

Bob

Improving communication with entanglement

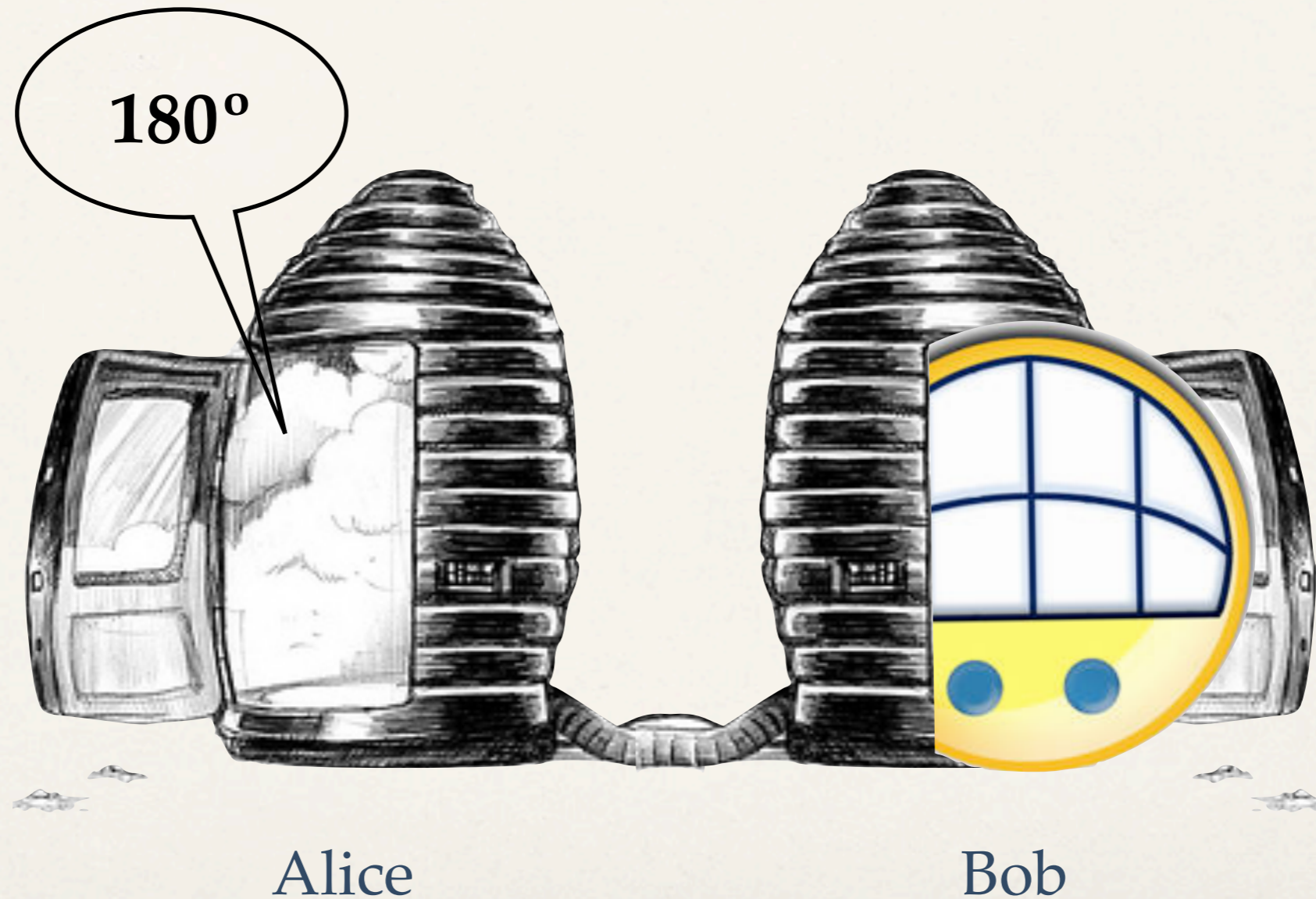


Alice

Bob

Improving communication with entanglement

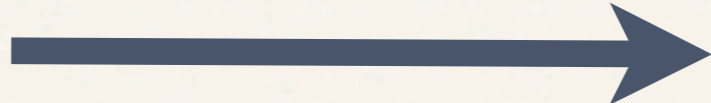
(d^2 possible rotations)



Improving communication with entanglement

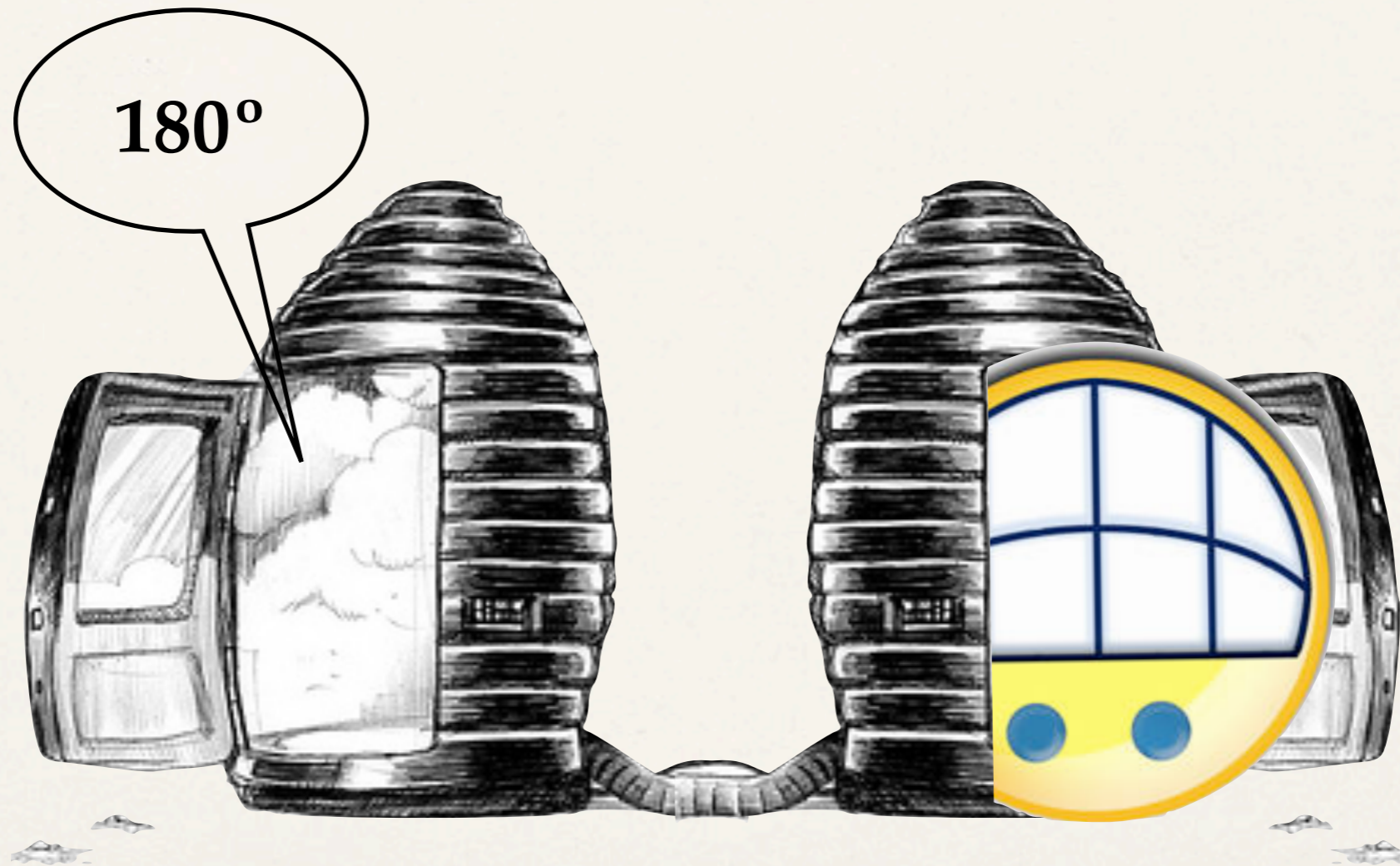
(d^2 possible rotations)

Classical message



Rotate by

180°



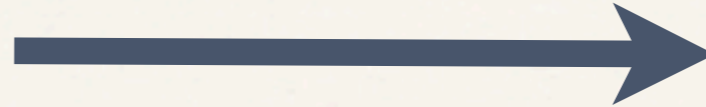
Alice

Bob

Improving communication with entanglement

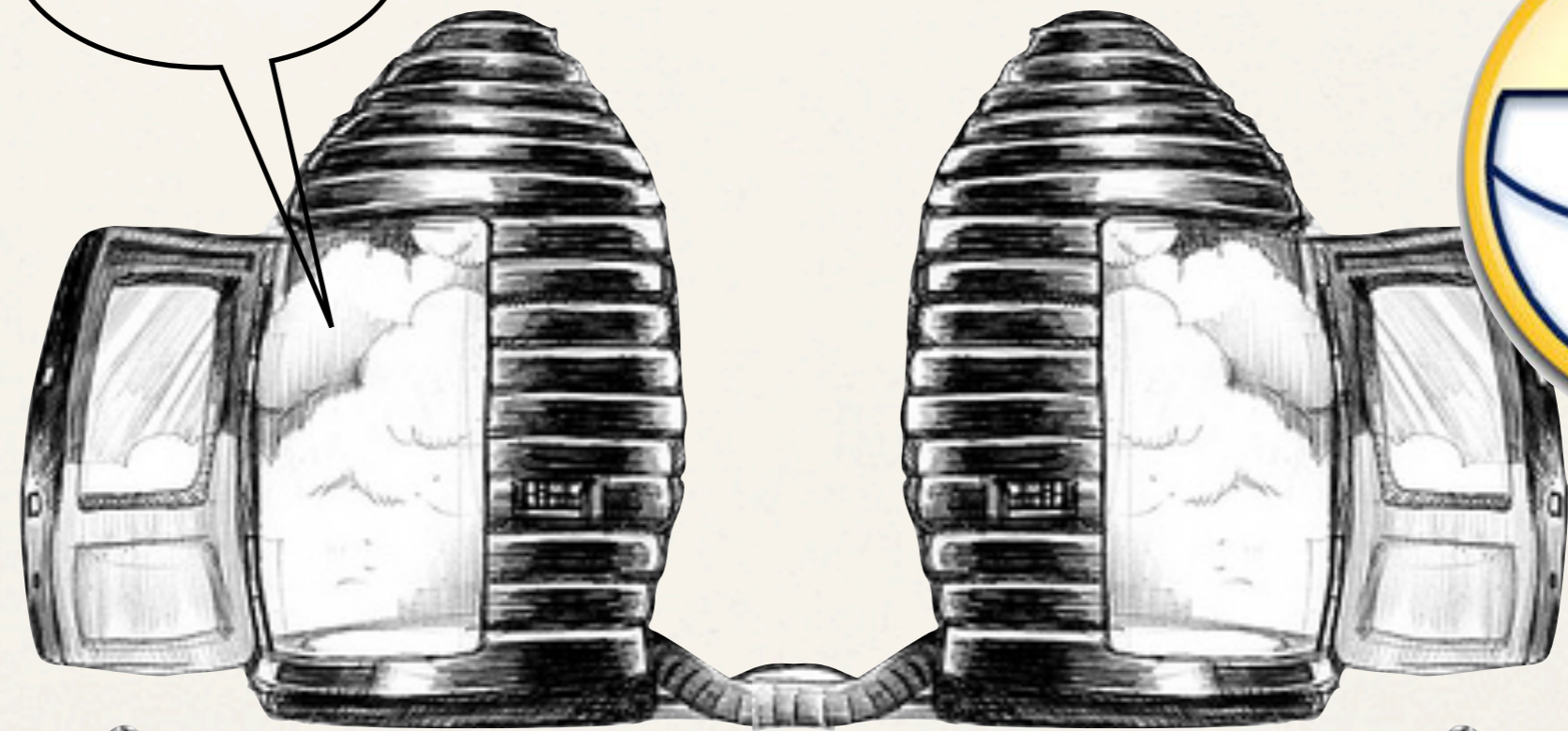
(d^2 possible rotations)

Classical message



Rotate by

180°



Alice

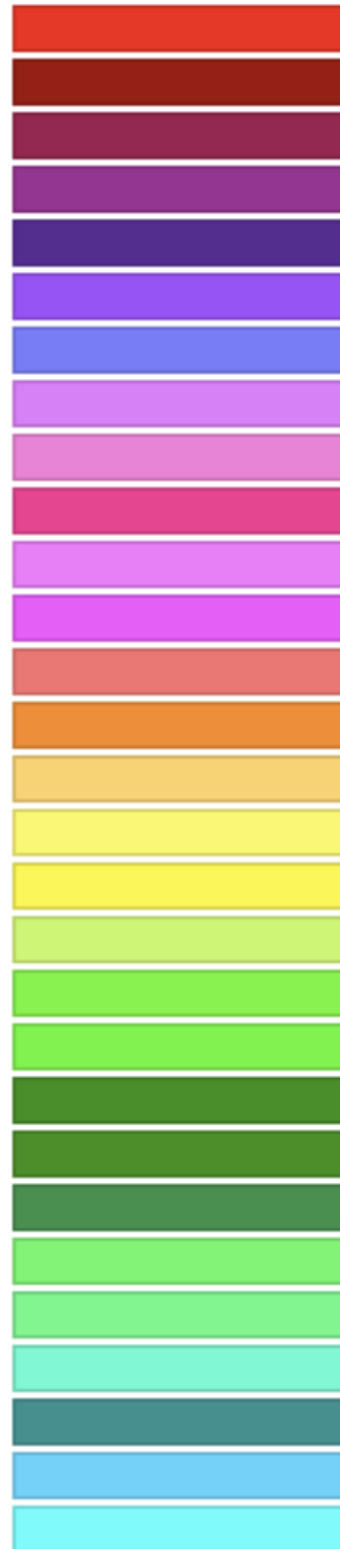
Bob



Improving communication with entanglement
































Improving communication with entanglement



Improving communication with entanglement

Color names if
you're a girl...



Maraschino	
Cayenne	
Maroon	
Plum	
Eggplant	
Grape	
Orchid	
Lavender	
Carnation	
Strawberry	
Bubblegum	
Magenta	
Salmon	
Tangerine	
Cantaloupe	
Banana	
Lemon	
Honeydew	
Lime	
Spring	
Clover	
Fern	
Moss	
Flora	
Sea Foam	
Spindrift	
Teal	
Sky	
Turquoise	

Improving communication with entanglement

Color names if you're a girl...



Maraschino		Red
Cayenne		
Maroon		Purple
Plum		
Eggplant		
Grape		
Orchid		Pink
Lavender		
Carnation		
Strawberry		
Bubblegum		Orange
Magenta		
Salmon		
Tangerine		
Cantaloupe		Yellow
Banana		
Lemon		Green
Honeydew		
Lime		
Spring		
Clover		Blue
Fern		
Moss		
Flora		
Sea Foam		
Spindrift		
Teal		
Sky		
Turquoise		

Color names if you're a guy...



Doghouse Diaries
"We take no as an answer."

Improving communication with entanglement

Color names if you're a girl...



Maraschino		Red
Cayenne		Purple
Maroon		
Plum		
Eggplant		
Grape		Pink
Orchid		
Lavender		
Carnation		
Strawberry		Orange
Bubblegum		
Magenta		Yellow
Salmon		
Tangerine		Green
Cantaloupe		
Banana		Blue
Lemon		
Honeydew		
Lime		
Spring		
Clover		
Fern		
Moss		
Flora		
Sea Foam		
Spindrift		
Teal		
Sky		
Turquoise		

Color names if you're a guy...



Doghouse Diaries
"We take no as an answer."

Improving communication with entanglement

Color names if you're a girl...



Maraschino		Red
Cayenne		
Maroon		Purple
Plum		
Eggplant		
Grape		
Orchid		Pink
Lavender		
Carnation		
Strawberry		
Bubblegum		Orange
Magenta		
Salmon		
Tangerine		Yellow
Cantaloupe		
Banana		Green
Lemon		
Honeydew		
Lime		
Spring		Blue
Clover		
Fern		
Moss		
Flora		
Sea Foam		
Spindrift		
Teal		
Sky		
Turquoise		

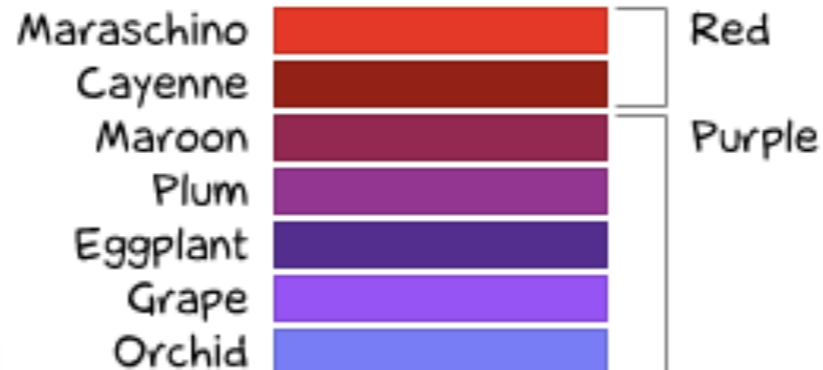
Color names if you're a guy...



Doghouse Diaries
"We take no as an answer."

Improving communication with entanglement

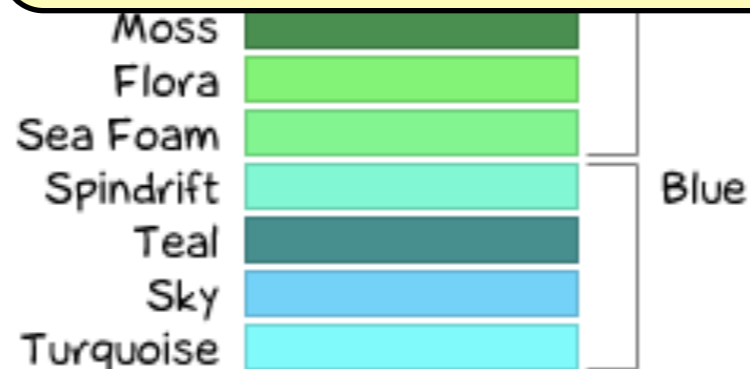
Color names if you're a girl...



Color names if you're a guy...



HOW MANY COLORS CAN ALICE SELECT WITHOUT RISK OF CONFUSION ON BOB'S SIDE?

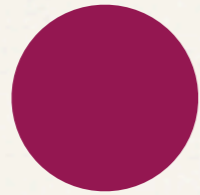


Doghouse Diaries
"We take no as an answer."

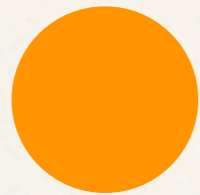
Improving communication with entanglement



Improving communication with entanglement



Purple



Red



Yellow

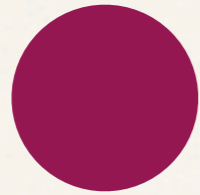


Green



Blue

Improving communication with entanglement



Purple



Red



Yellow

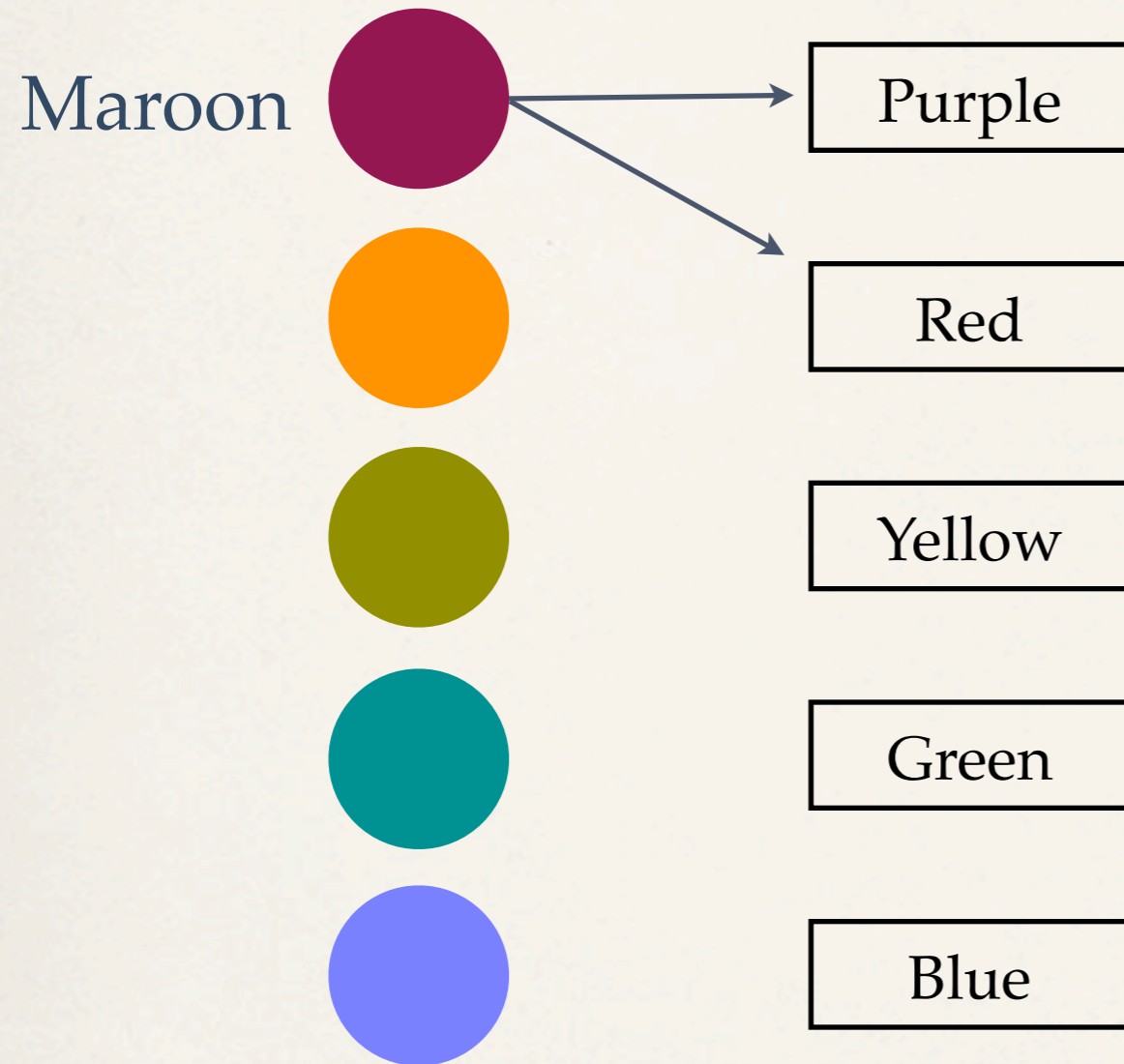


Green

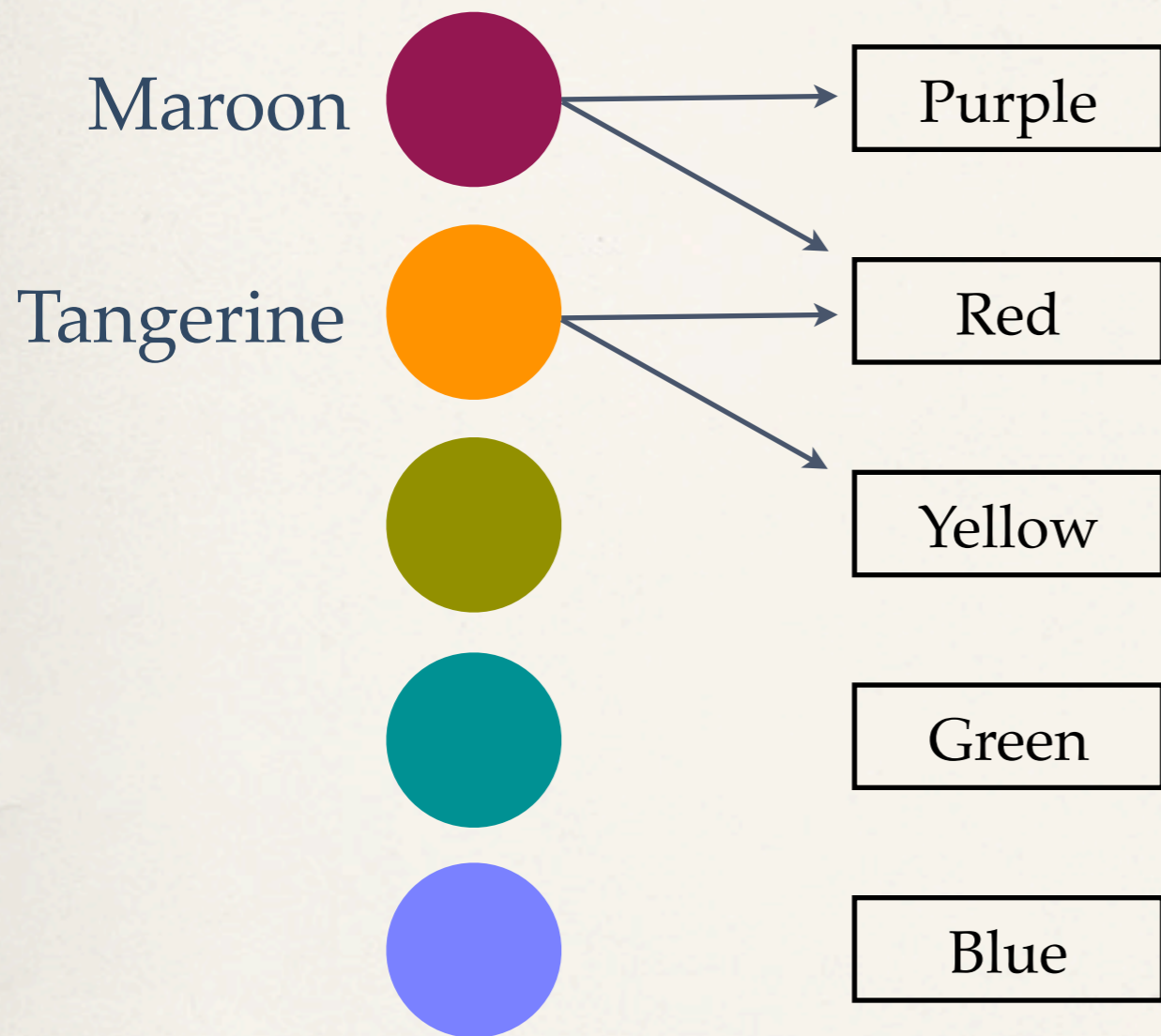


Blue

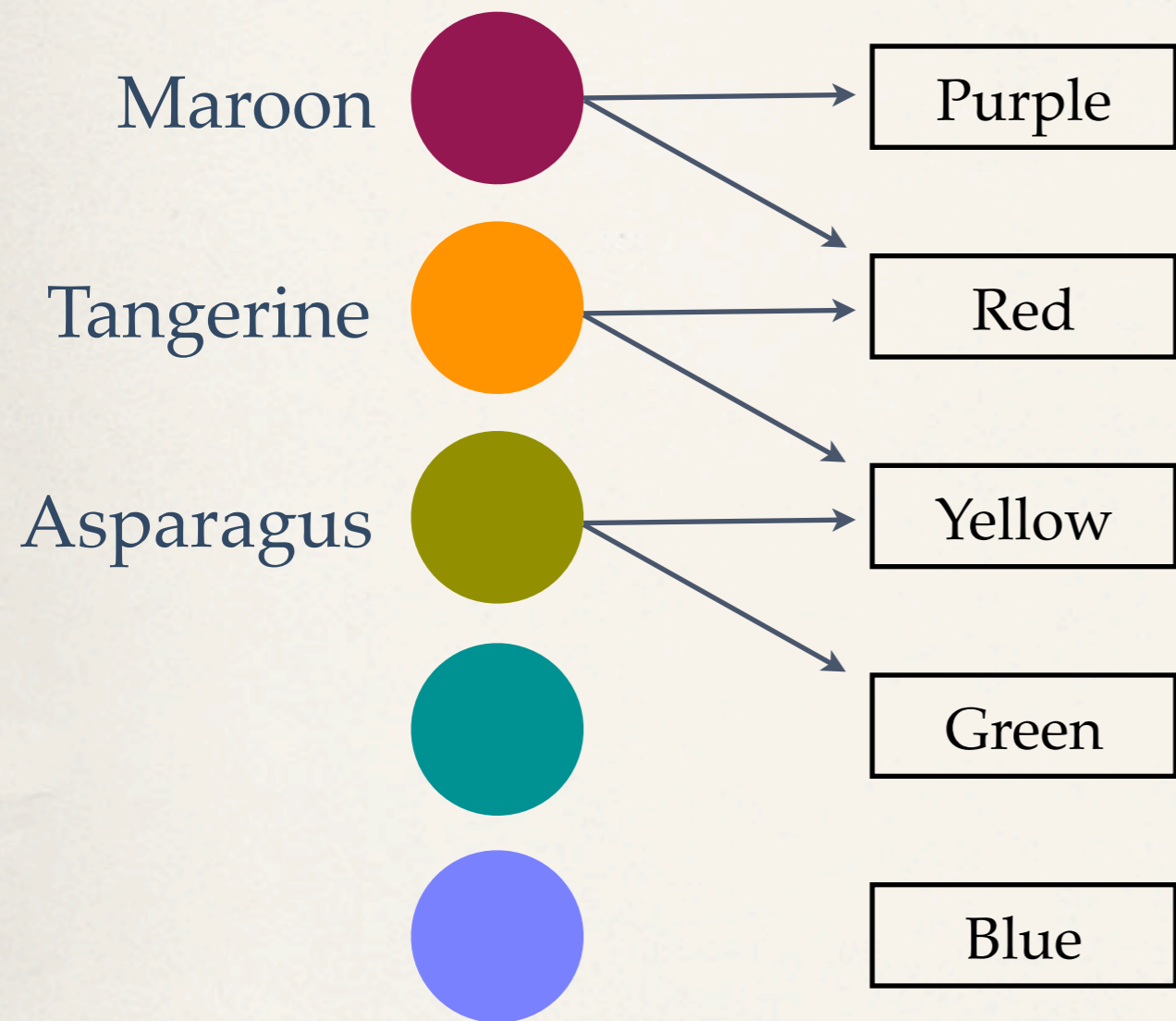
Improving communication with entanglement



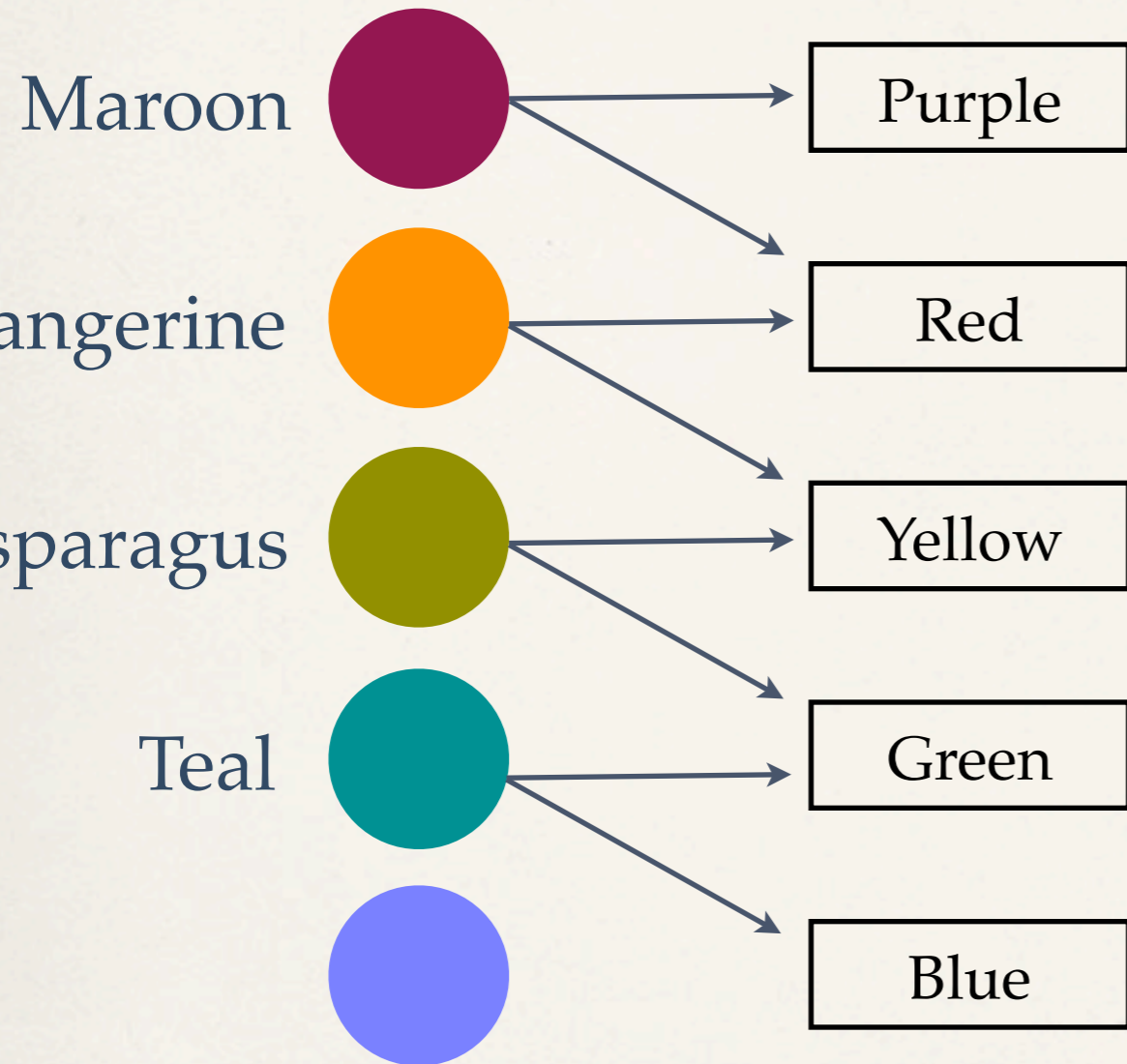
Improving communication with entanglement



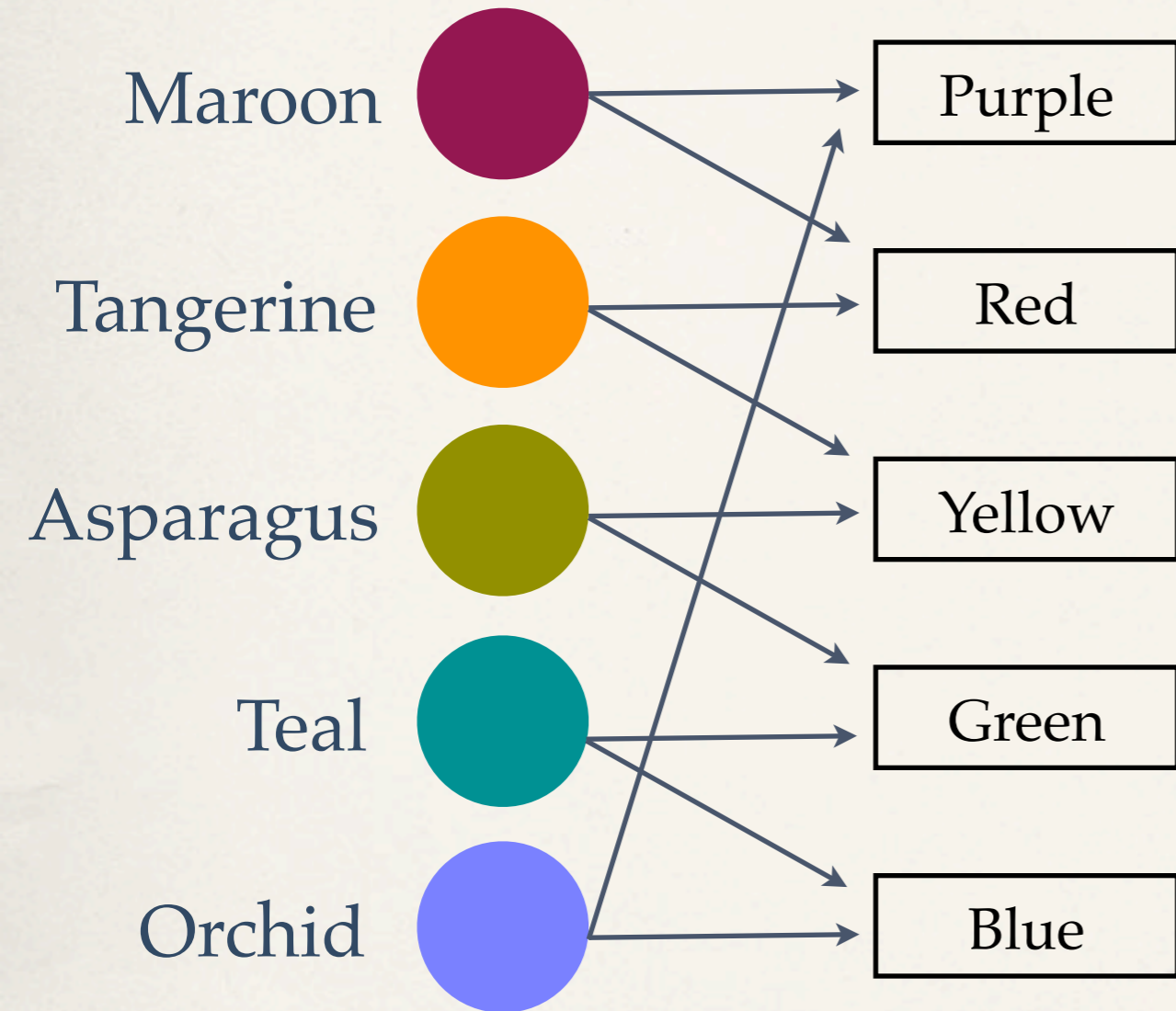
Improving communication with entanglement



Improving communication with entanglement

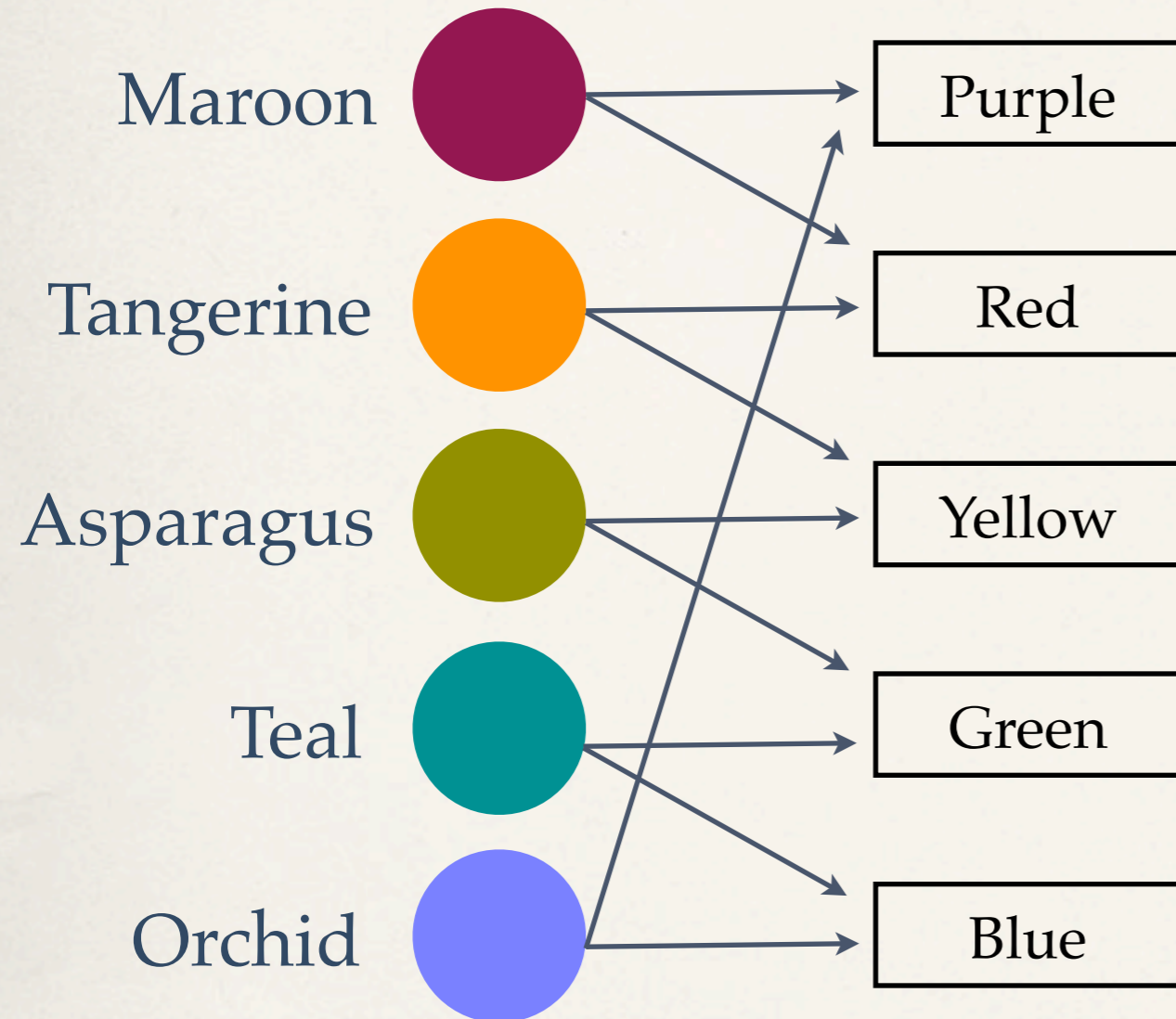


Improving communication with entanglement



Improving communication with entanglement

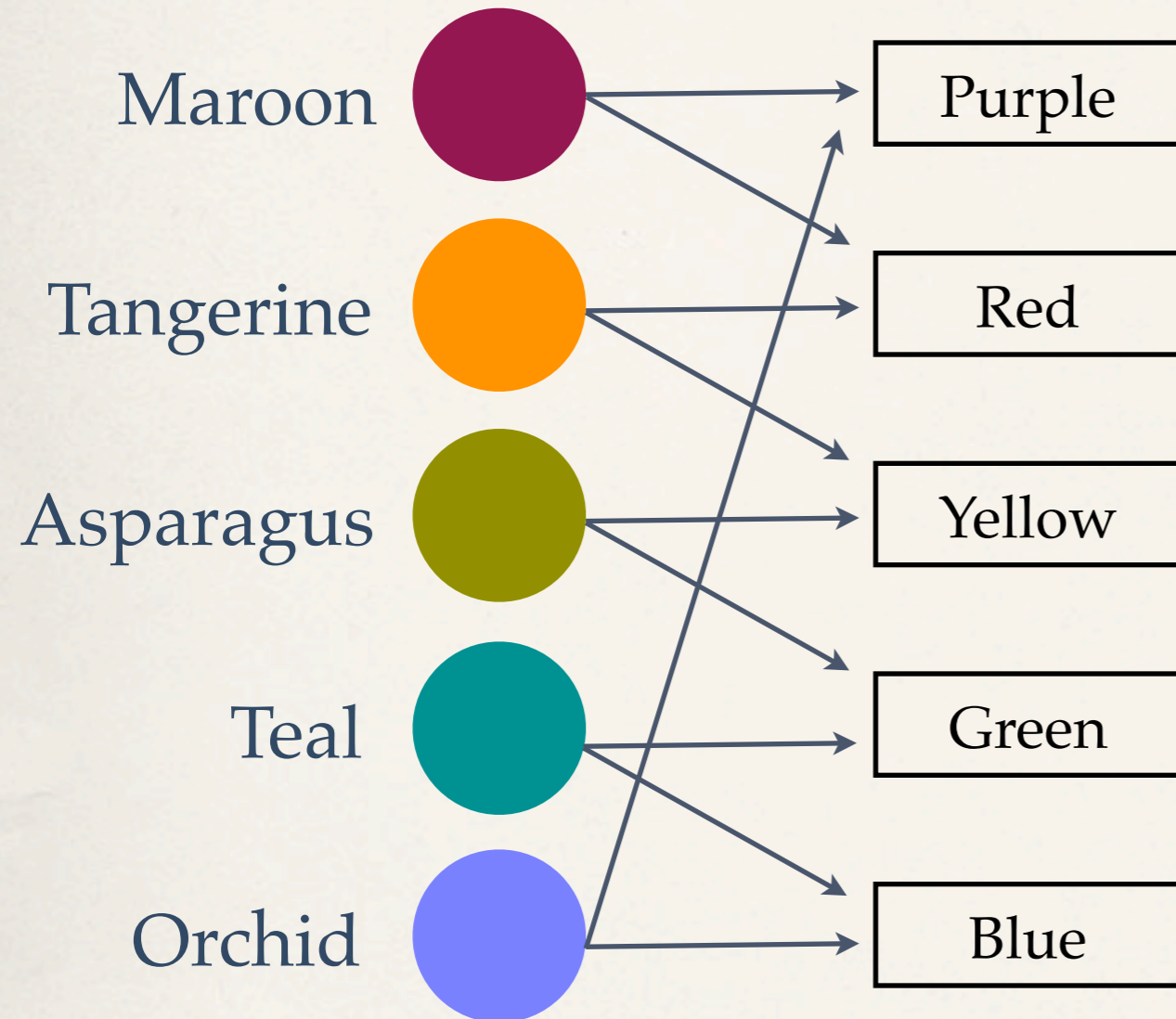
NOISY COMMUNICATION CHANNEL



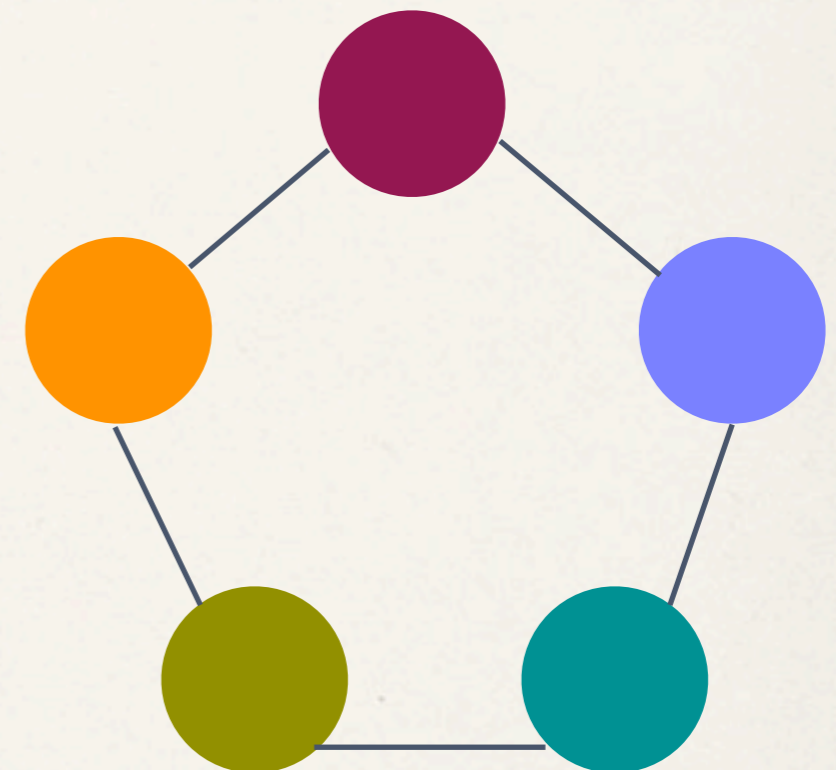
INPUT/OUTPUT GRAPH

Improving communication with entanglement

NOISY COMMUNICATION CHANNEL



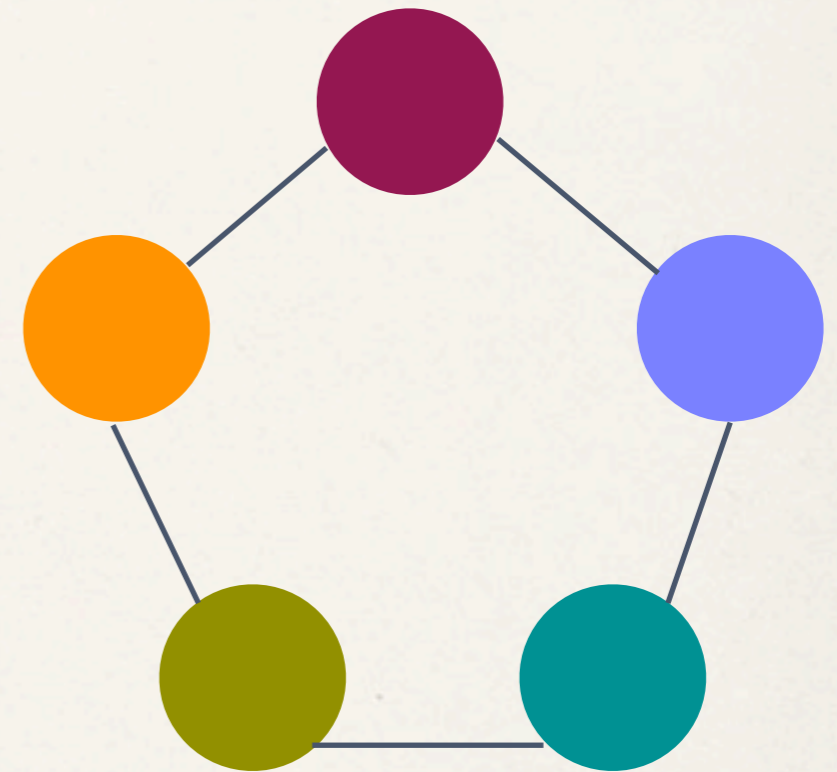
INPUT/OUTPUT GRAPH



CONFUSABILITY GRAPH

Improving communication with entanglement

NOISY COMMUNICATION CHANNEL

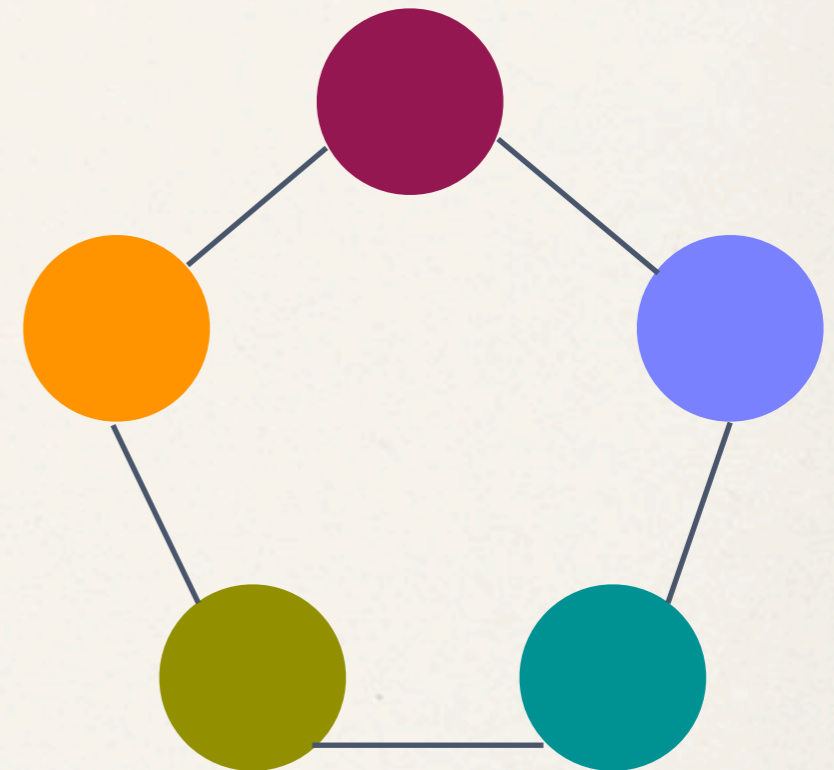


CONFUSABILITY GRAPH

Improving communication with entanglement

NOISY COMMUNICATION CHANNEL

HOW MANY
COLORS CAN
ALICE SELECT
*WITHOUT RISK OF
CONFUSION ON
BOB'S SIDE?*



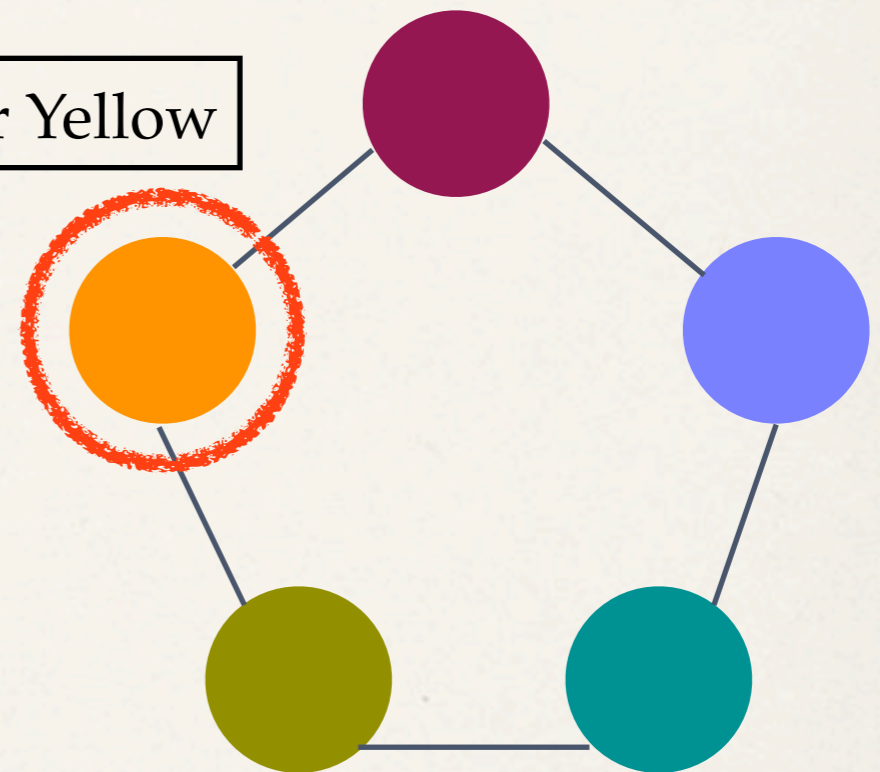
CONFUSABILITY GRAPH

Improving communication with entanglement

NOISY COMMUNICATION CHANNEL

HOW MANY
COLORS CAN
ALICE SELECT
*WITHOUT RISK OF
CONFUSION ON
BOB'S SIDE?*

Red or Yellow

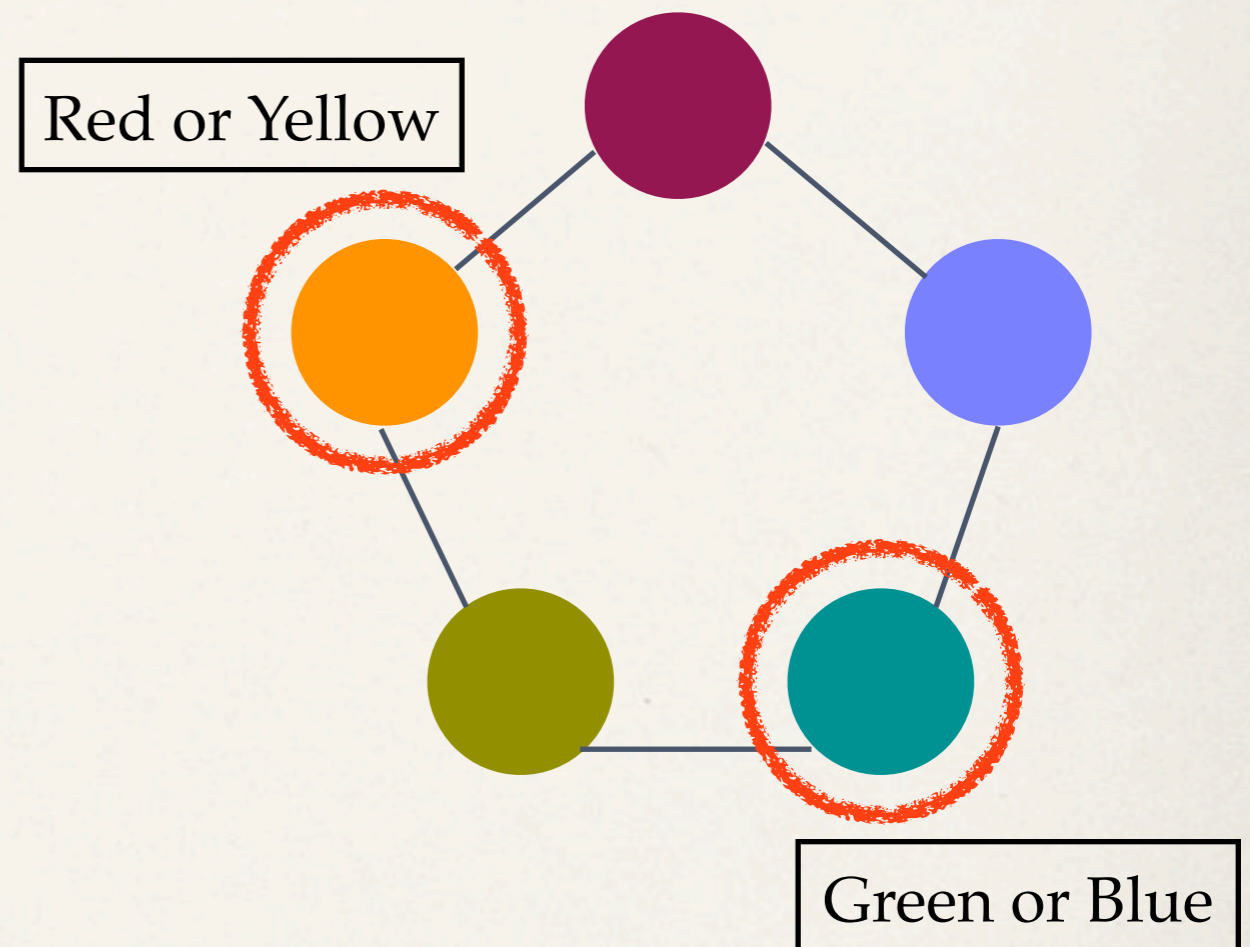


CONFUSABILITY GRAPH

Improving communication with entanglement

NOISY COMMUNICATION CHANNEL

HOW MANY
COLORS CAN
ALICE SELECT
*WITHOUT RISK OF
CONFUSION ON
BOB'S SIDE?*

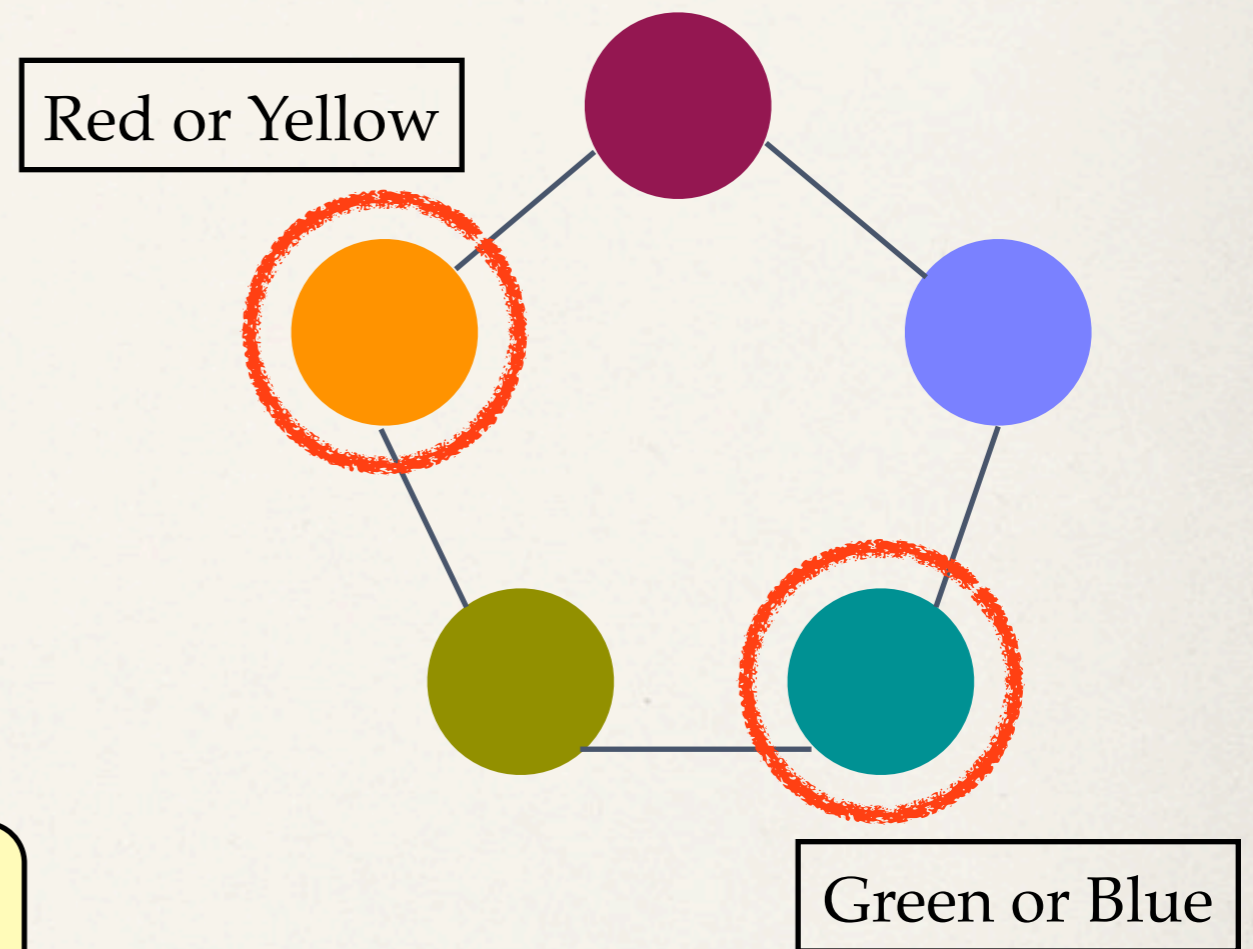


CONFUSABILITY GRAPH

Improving communication with entanglement

NOISY COMMUNICATION CHANNEL

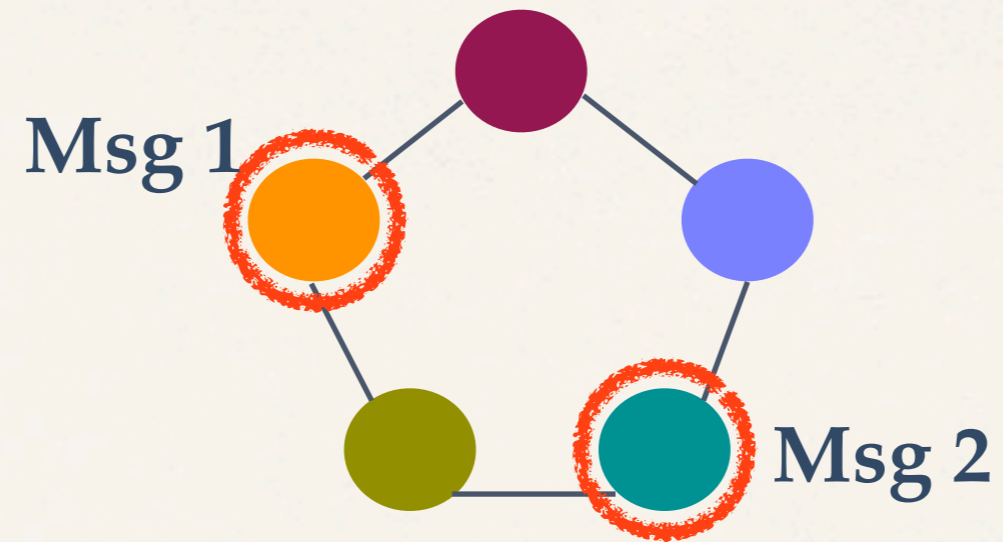
HOW MANY
COLORS CAN
ALICE SELECT
*WITHOUT RISK OF
CONFUSION ON
BOB'S SIDE?*



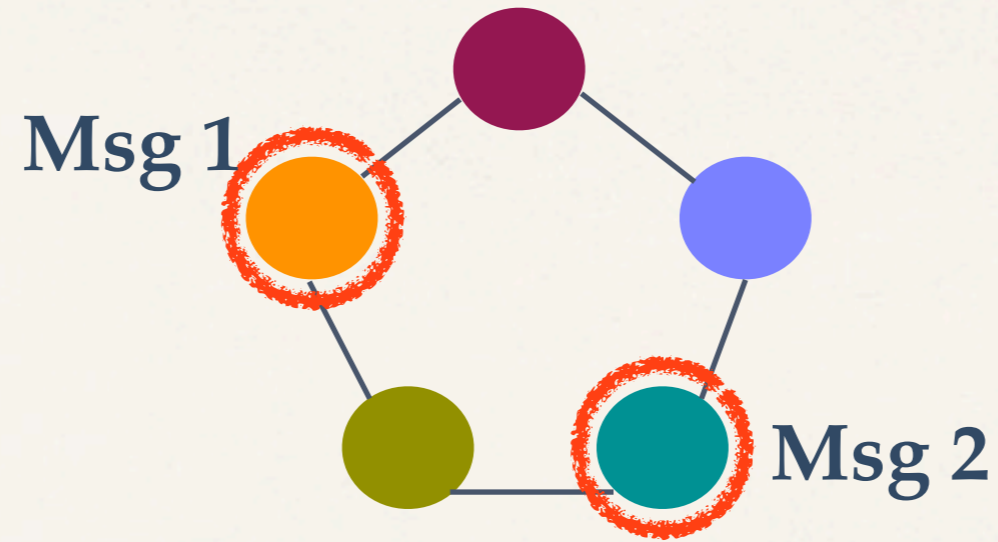
THE INDEPENDENCE NUMBER
(NP-hard problem)

CONFUSABILITY GRAPH

Improving communication with entanglement



Improving communication with entanglement

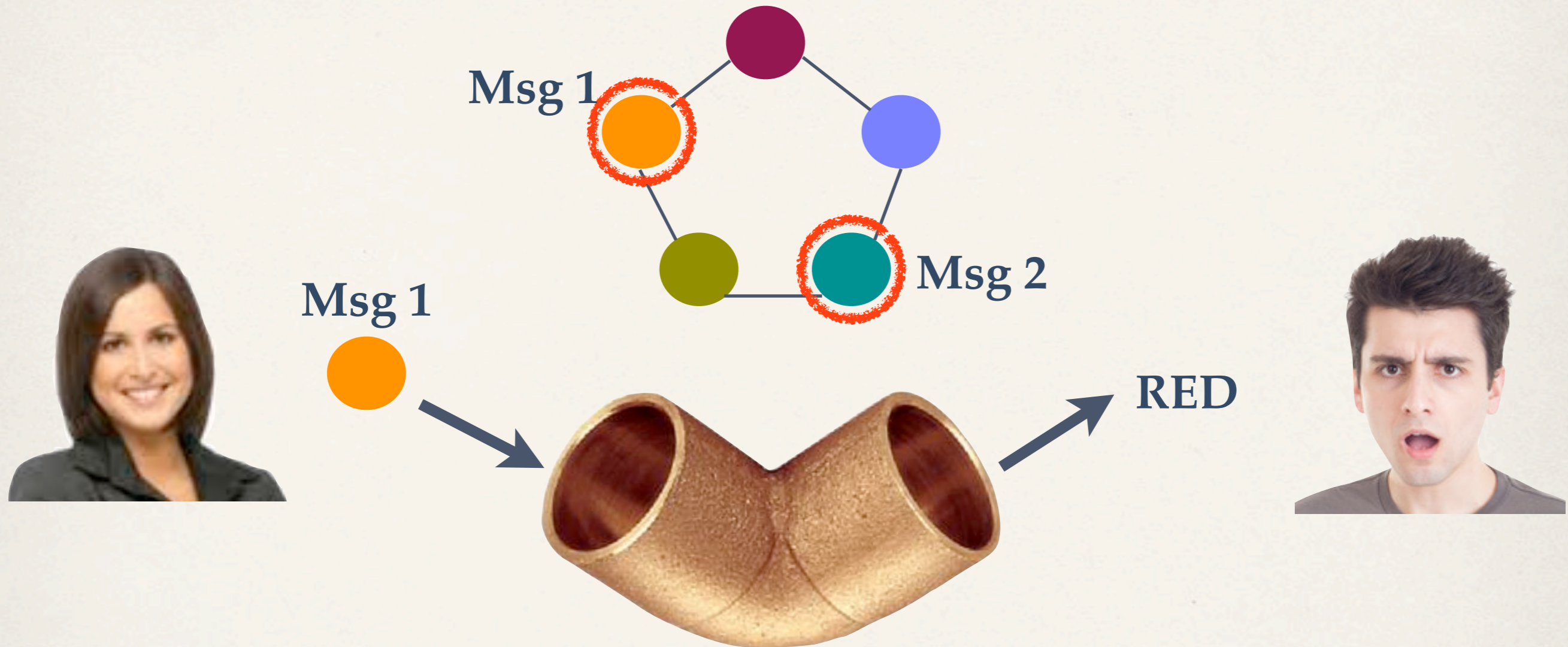


Msg 1

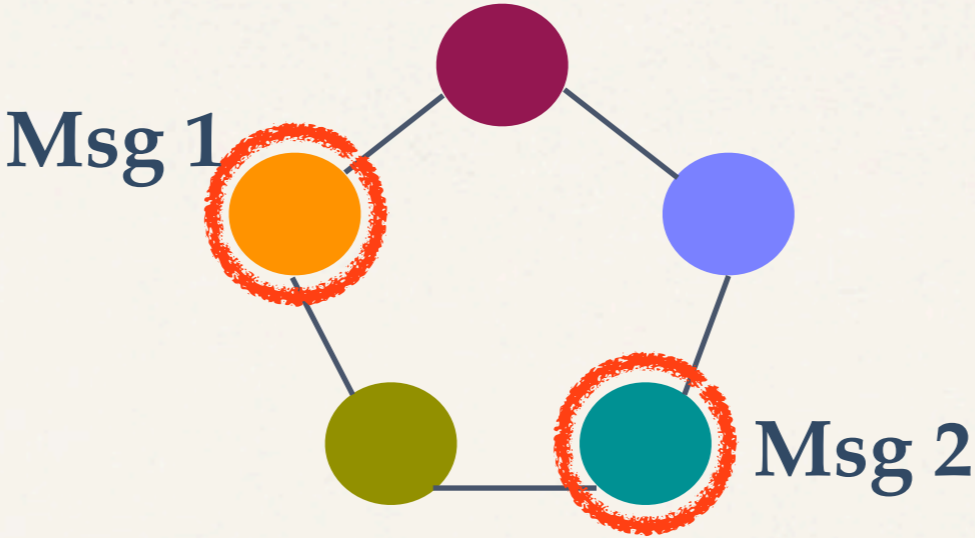
Msg 2



Improving communication with entanglement



Improving communication with entanglement



Msg 1



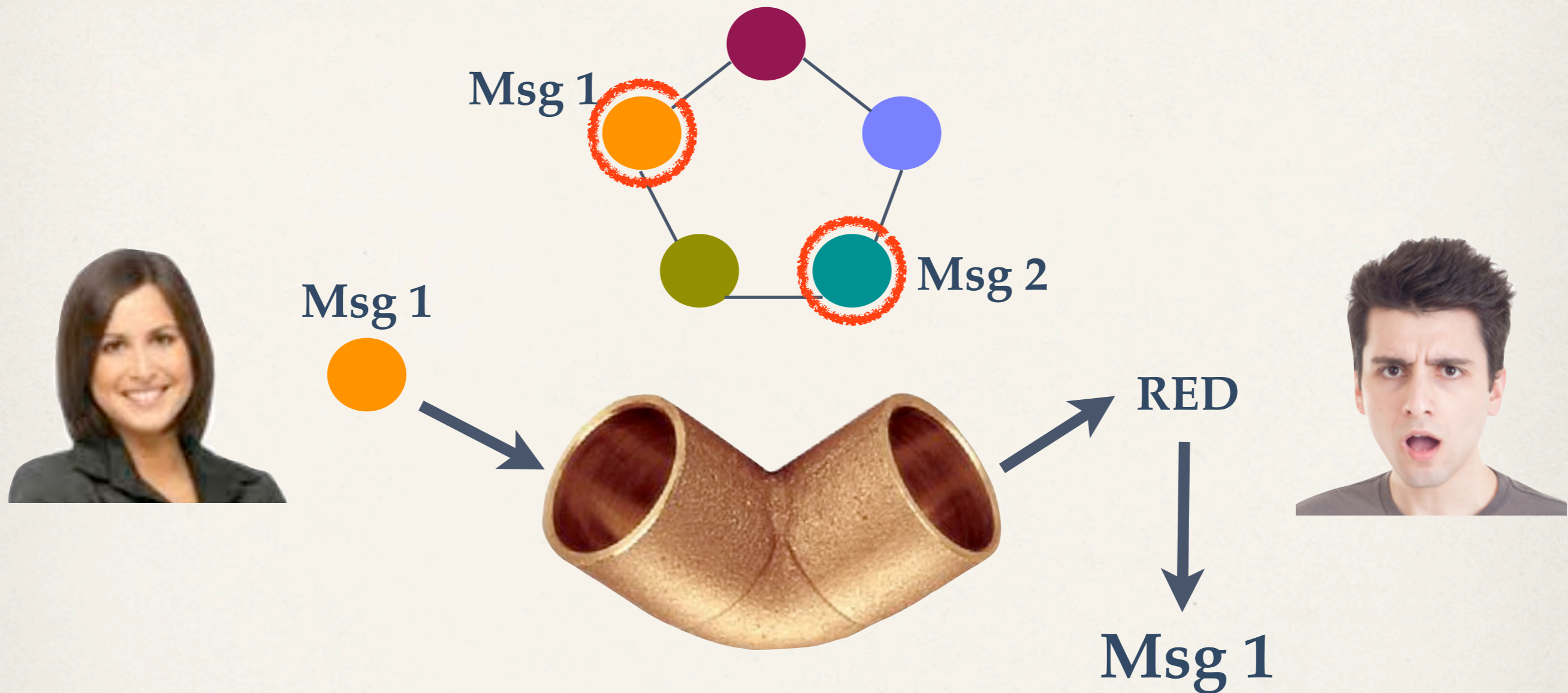
RED



Msg 1



Improving communication with entanglement

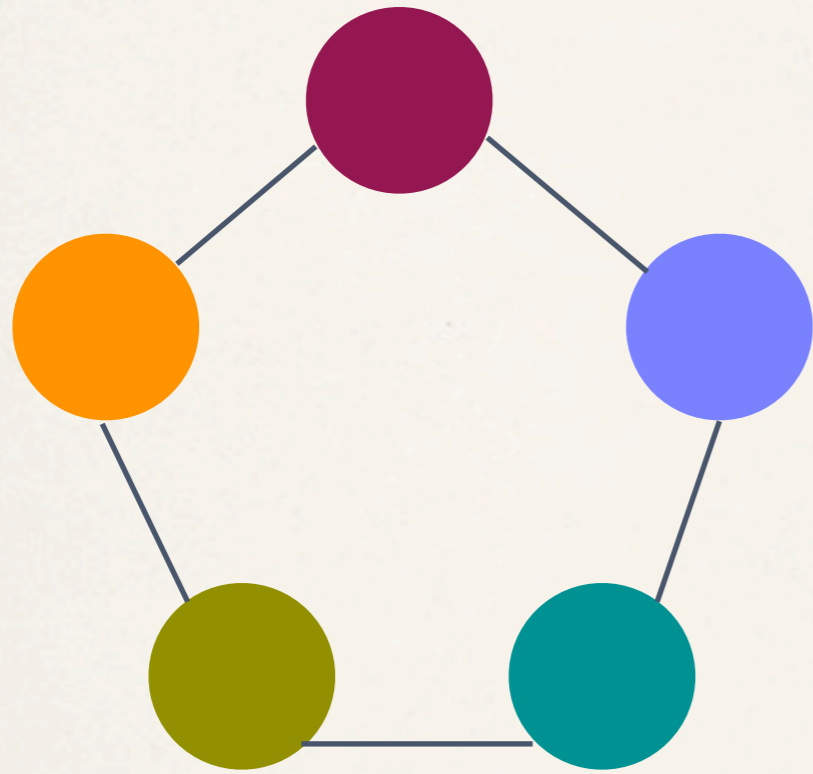


- * *Zero-error Shannon capacity:*
average #messages per use of the channel

Improving communication with entanglement

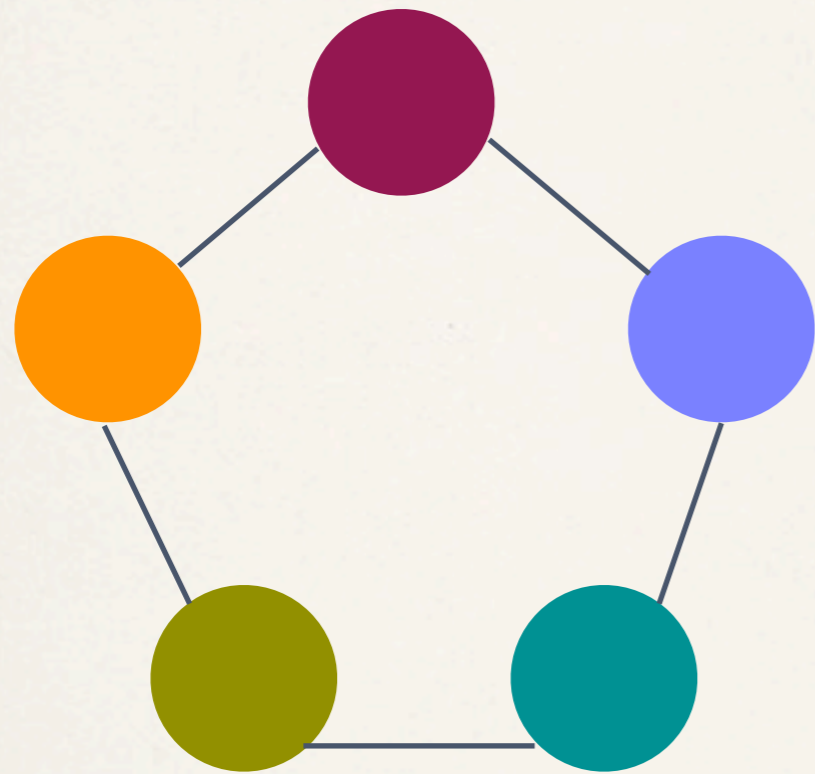


Improving communication with entanglement



CONFUSABILITY GRAPH
of the channel

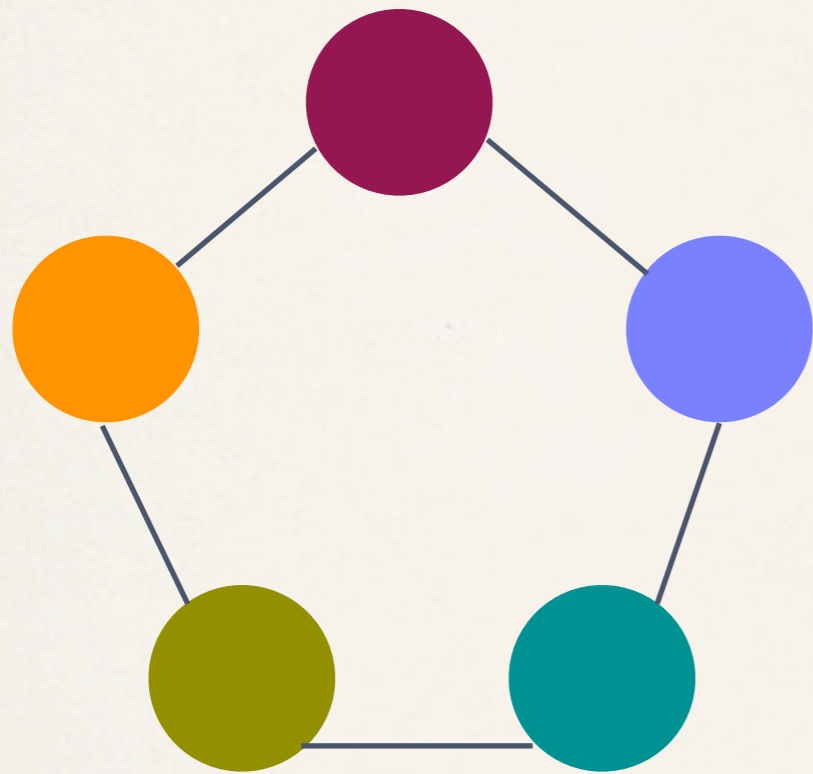
Improving communication with entanglement



✦ α : independence number

CONFUSABILITY GRAPH
of the channel

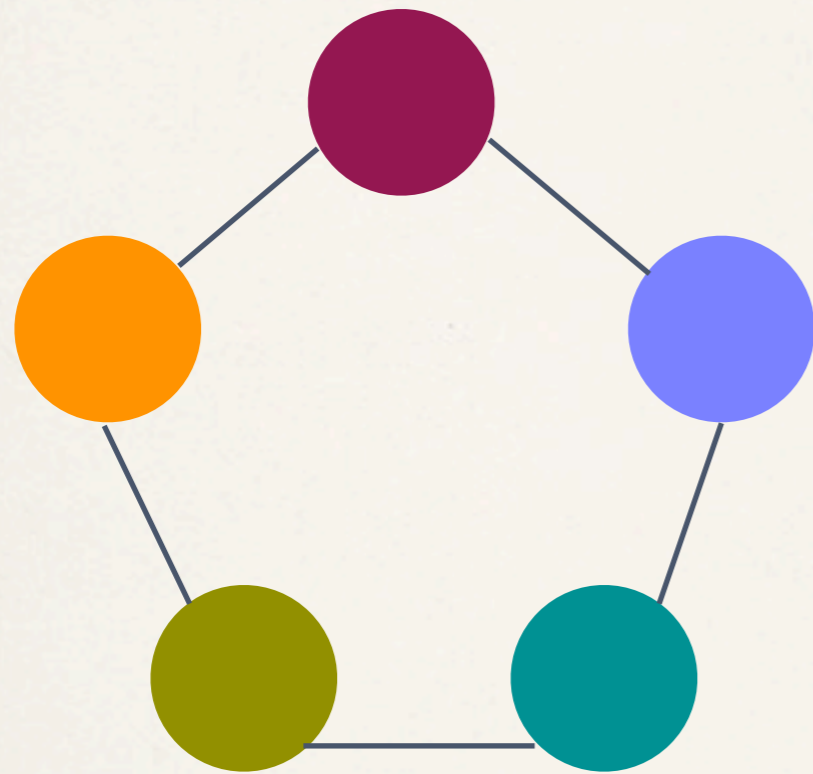
Improving communication with entanglement



- * α : independence number
- * d : minimum dimension of *orthogonal representation*:
vectors $v(u), v(w), \dots$
orthogonal if (u,w) is an edge

CONFUSABILITY GRAPH
of the channel

Improving communication with entanglement

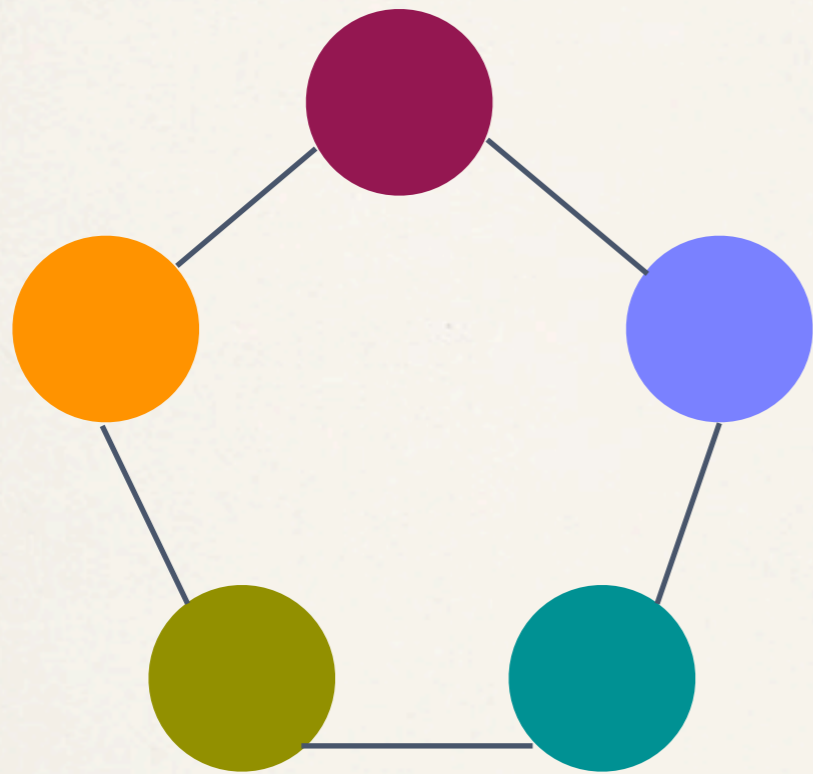


- * α : independence number
- * d : minimum dimension of *orthogonal representation*:
vectors $v(u), v(w), \dots$
orthogonal if (u,w) is an edge

CONFUSABILITY GRAPH
of the channel

* Quantum states are **vectors**

Improving communication with entanglement

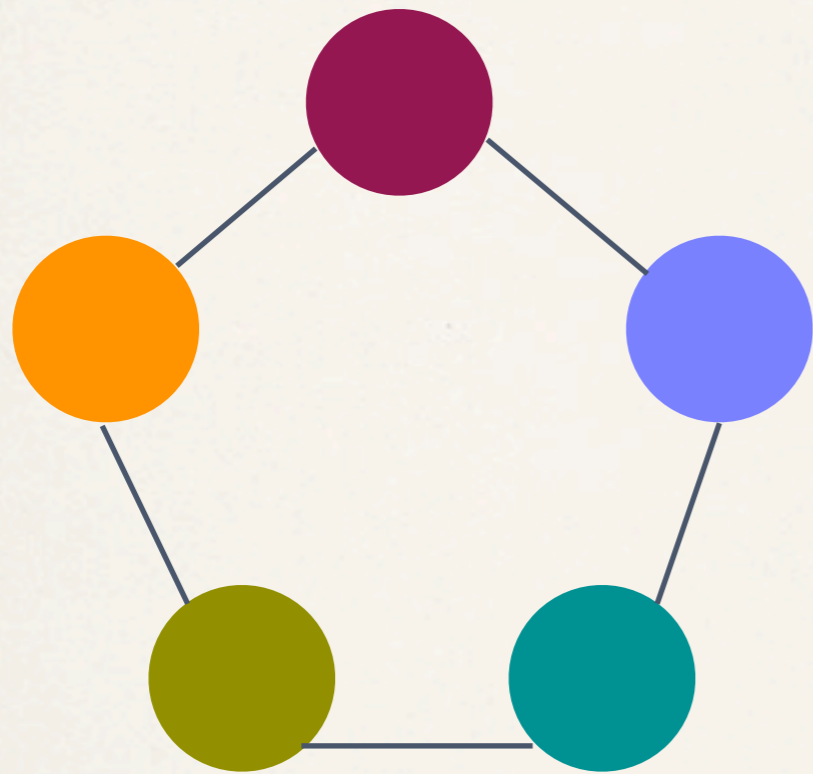


- * α : independence number
- * d : minimum dimension of *orthogonal representation*:
vectors $v(u), v(w), \dots$
orthogonal if (u,w) is an edge

CONFUSABILITY GRAPH
of the channel

- * Quantum states are **vectors**
- * **Distinguishable** if orthogonal

Improving communication with entanglement

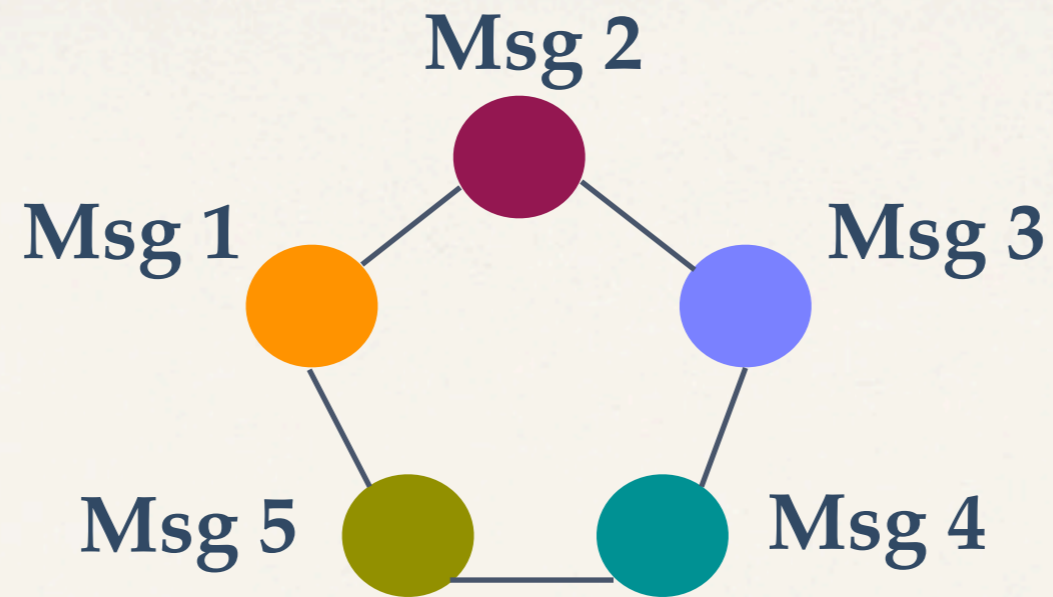


- * α : independence number
- * d : minimum dimension of *orthogonal representation*:
vectors $v(u), v(w), \dots$
orthogonal if (u,w) is an edge

CONFUSABILITY GRAPH
of the channel

- * Quantum states are **vectors**
- * **Distinguishable** if orthogonal
- * **Teleport** d -dim state by sending **one** out of d^2 classical messages

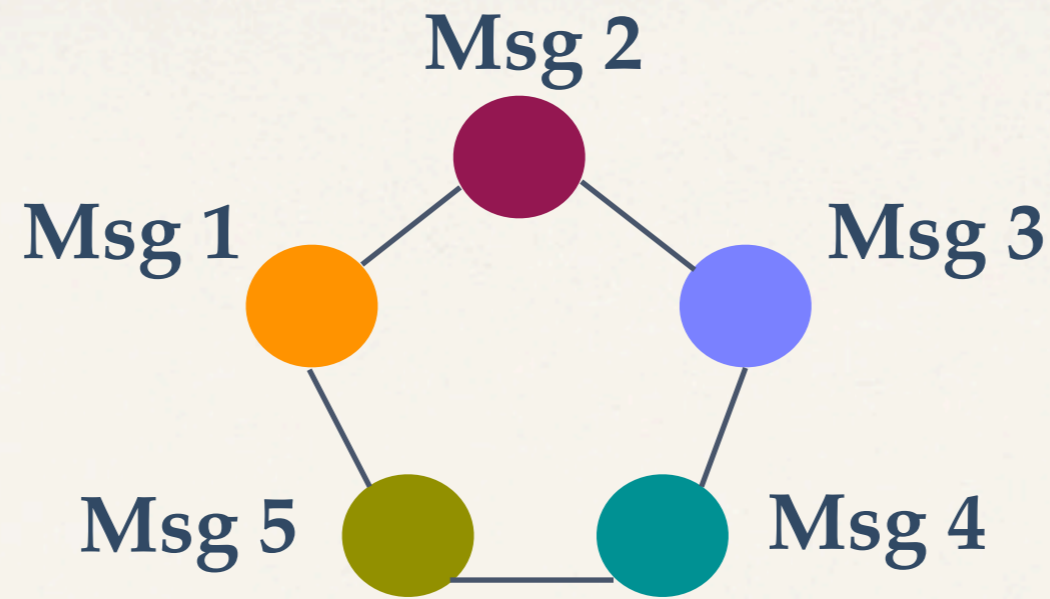
Improving communication with entanglement



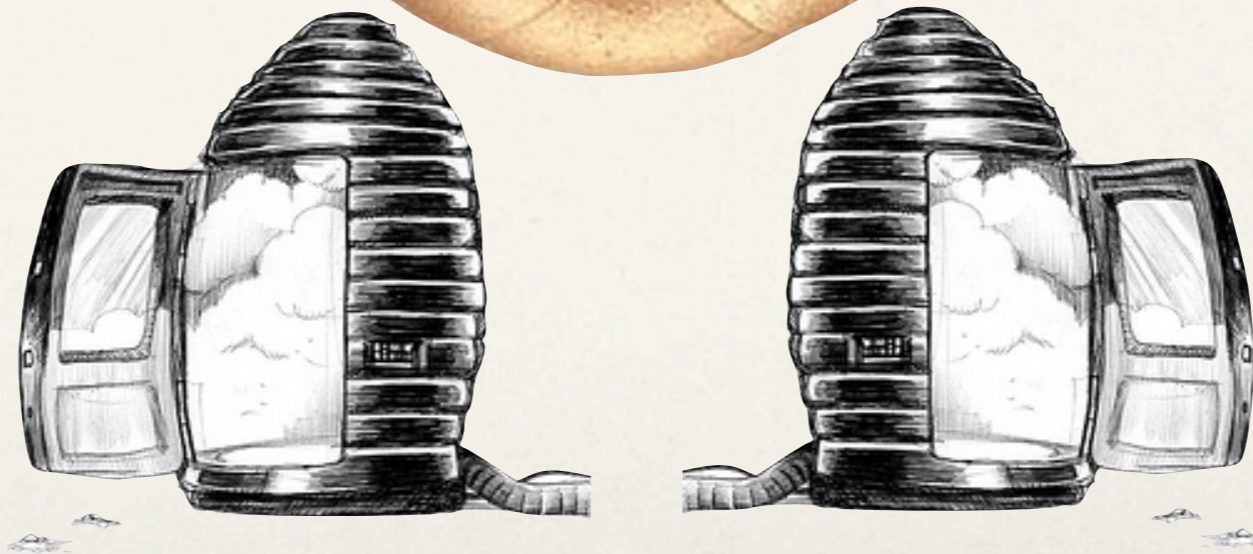
Msg 1



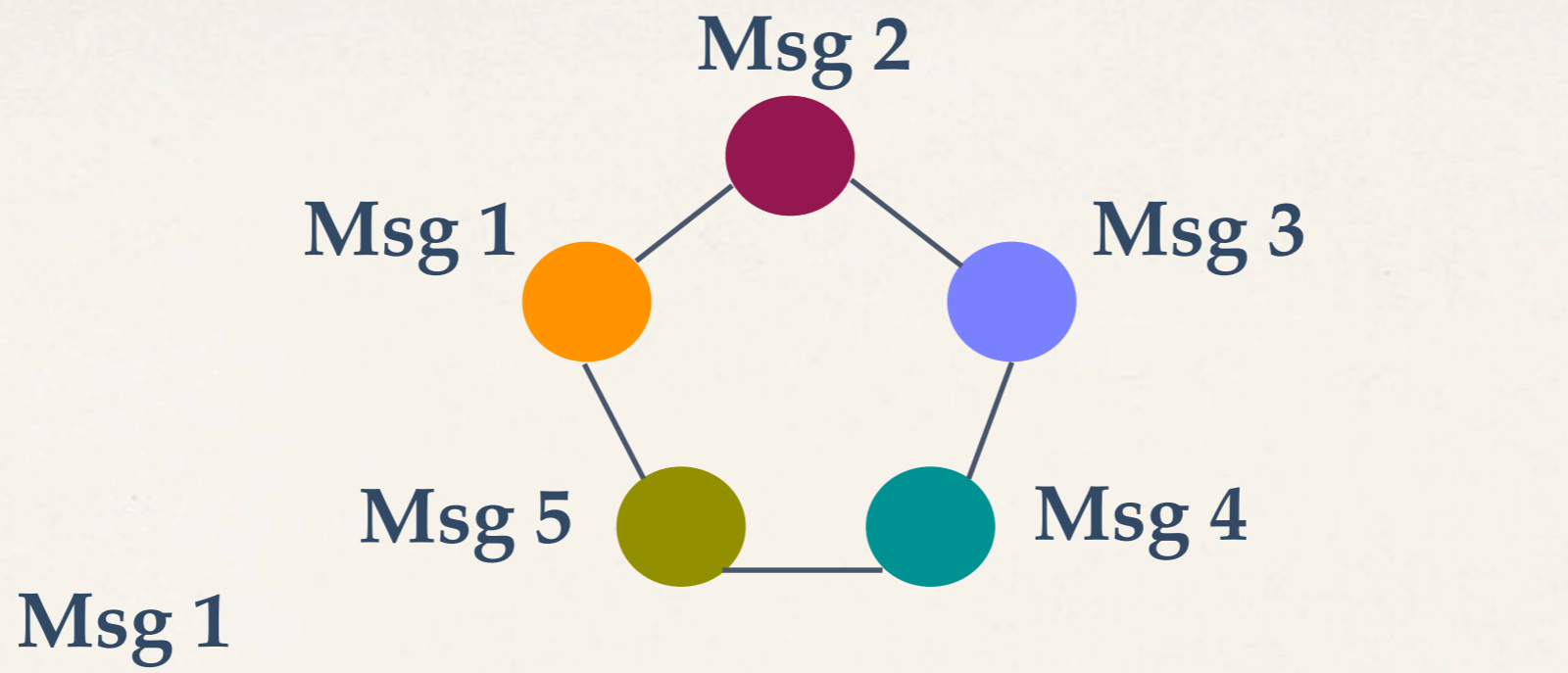
Improving communication with entanglement



Msg 1



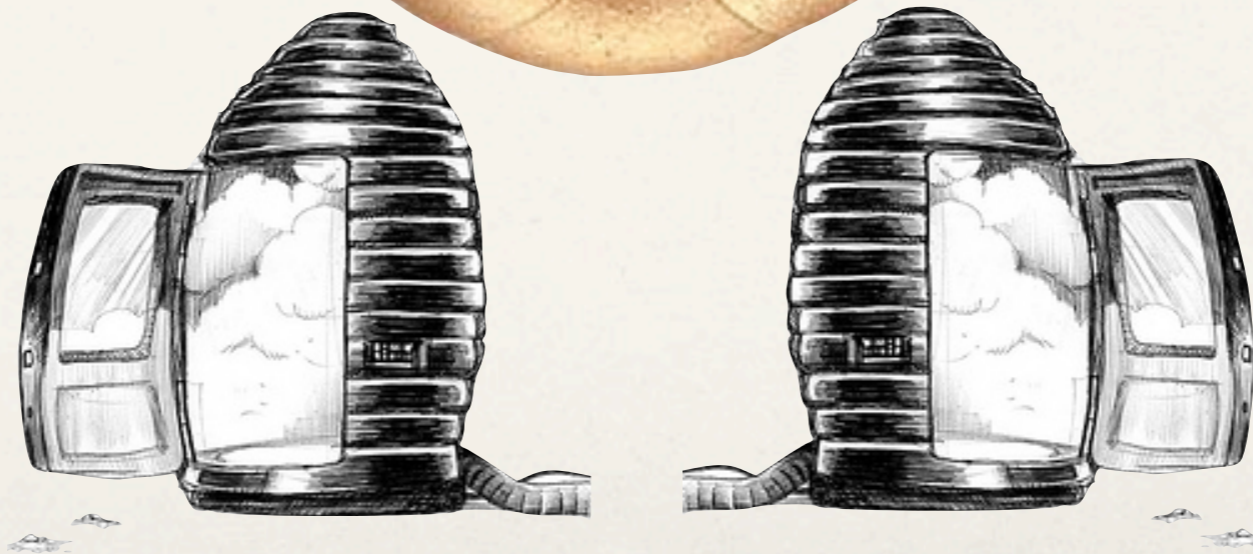
Improving communication with entanglement



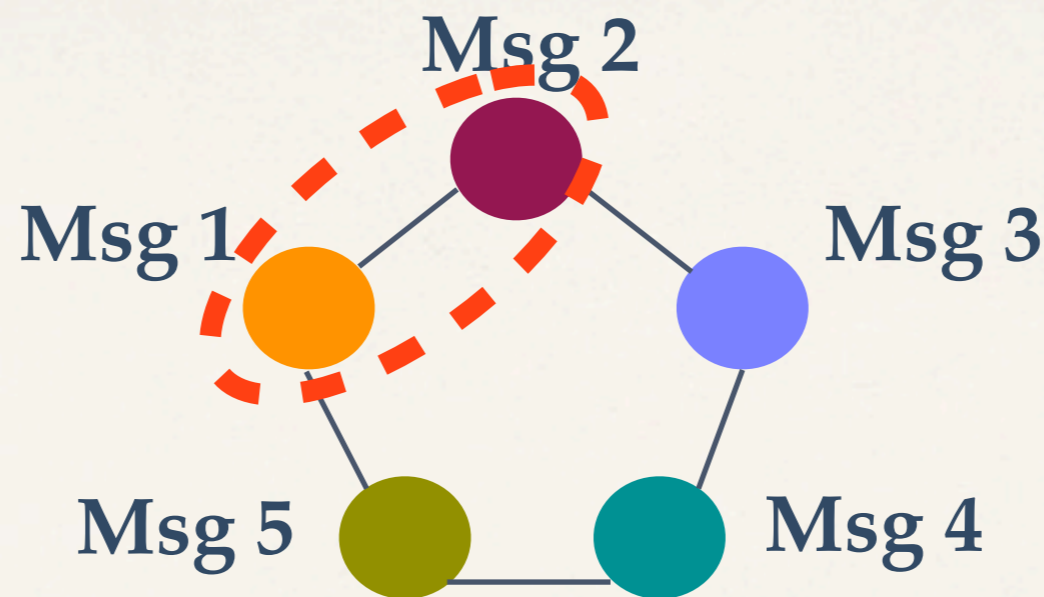
Msg 1



RED



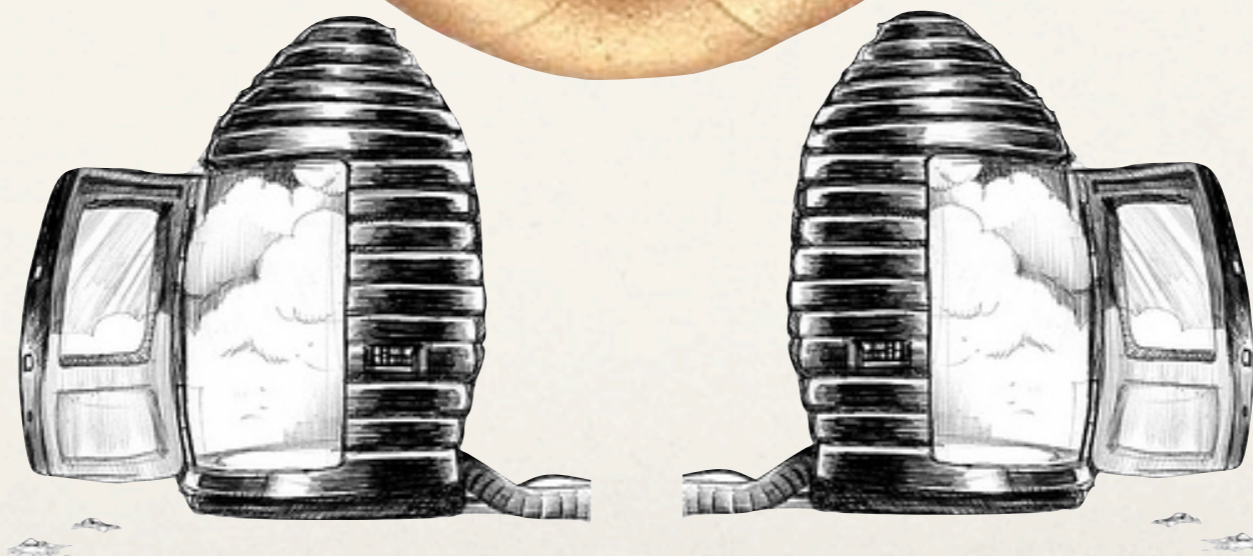
Improving communication with entanglement



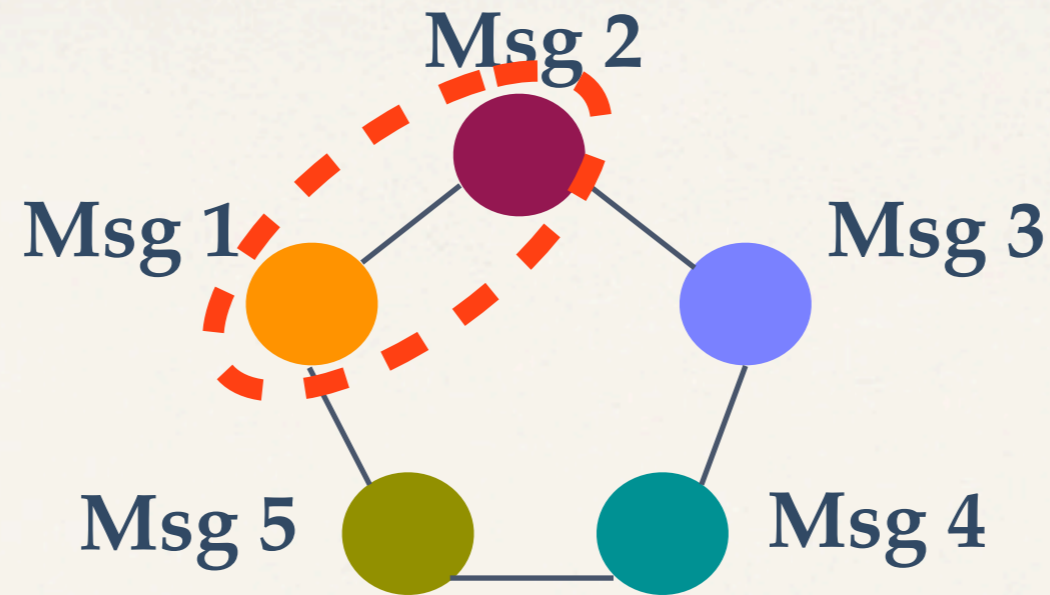
Msg 1



RED



Improving communication with entanglement



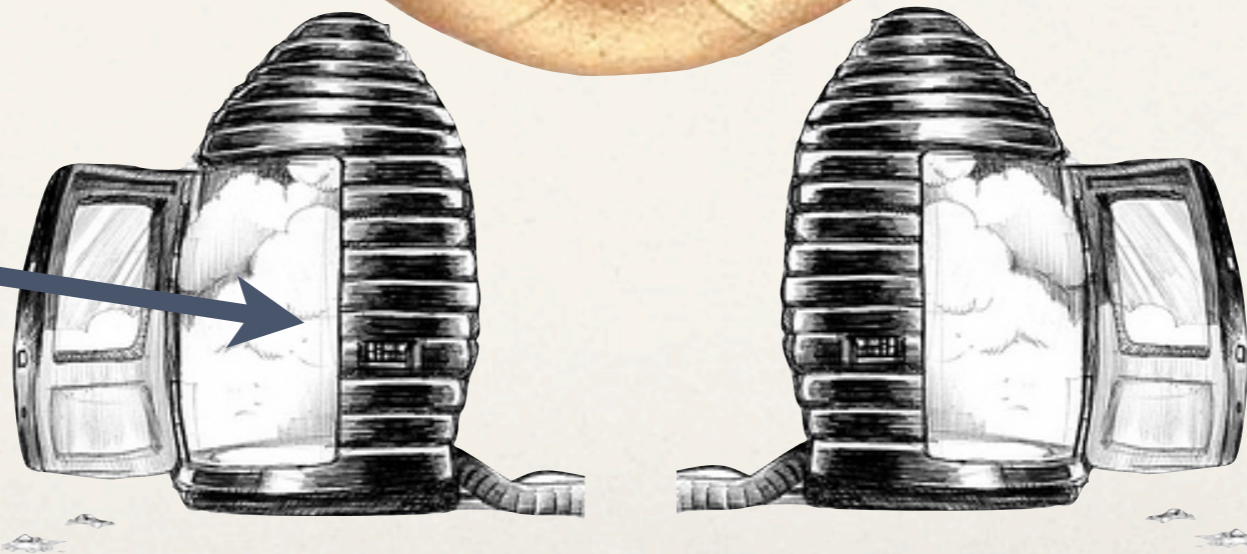
Msg 1



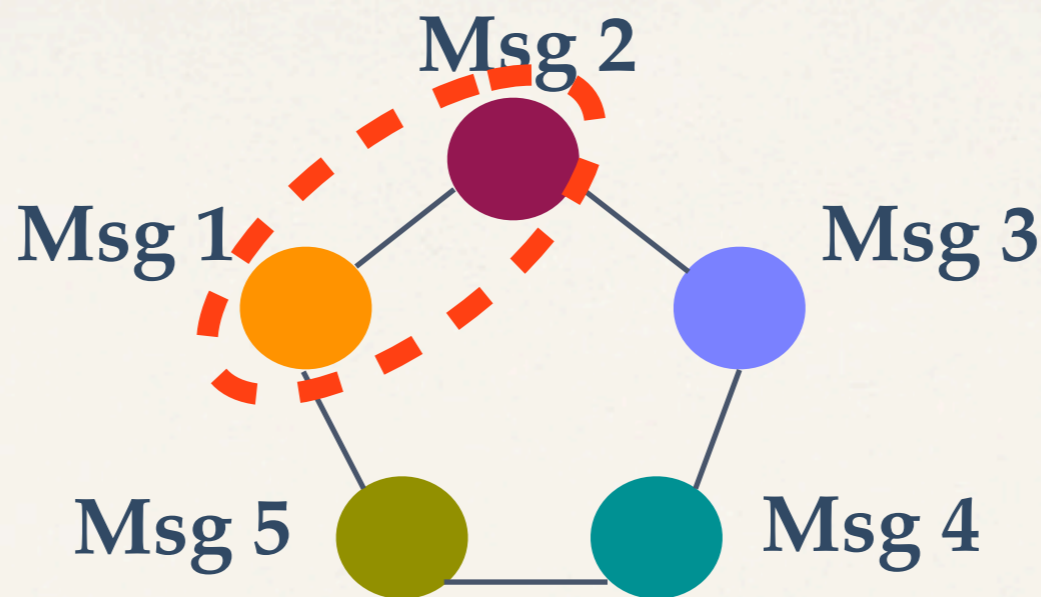
RED



$v(\bullet)$



Improving communication with entanglement



Msg 1

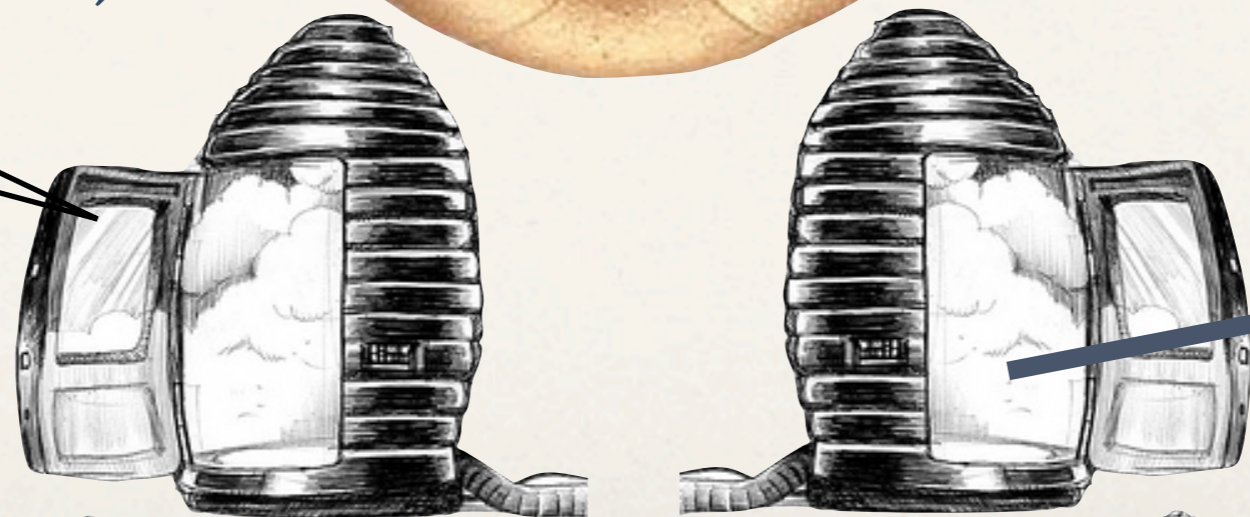


RED

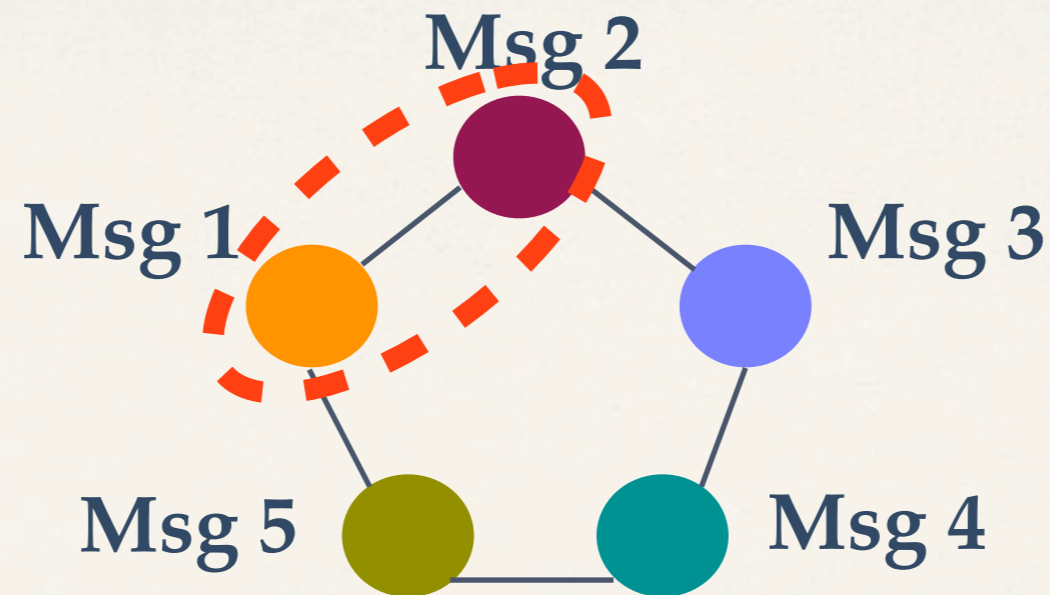


(one rotation out of d^2)

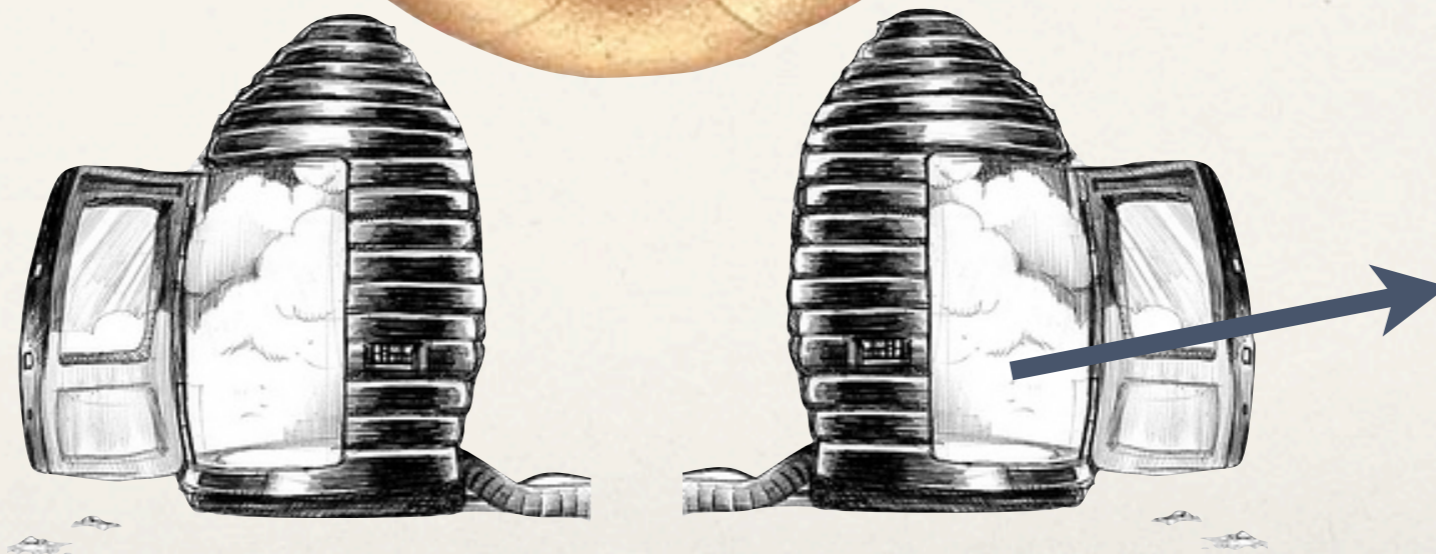
90°



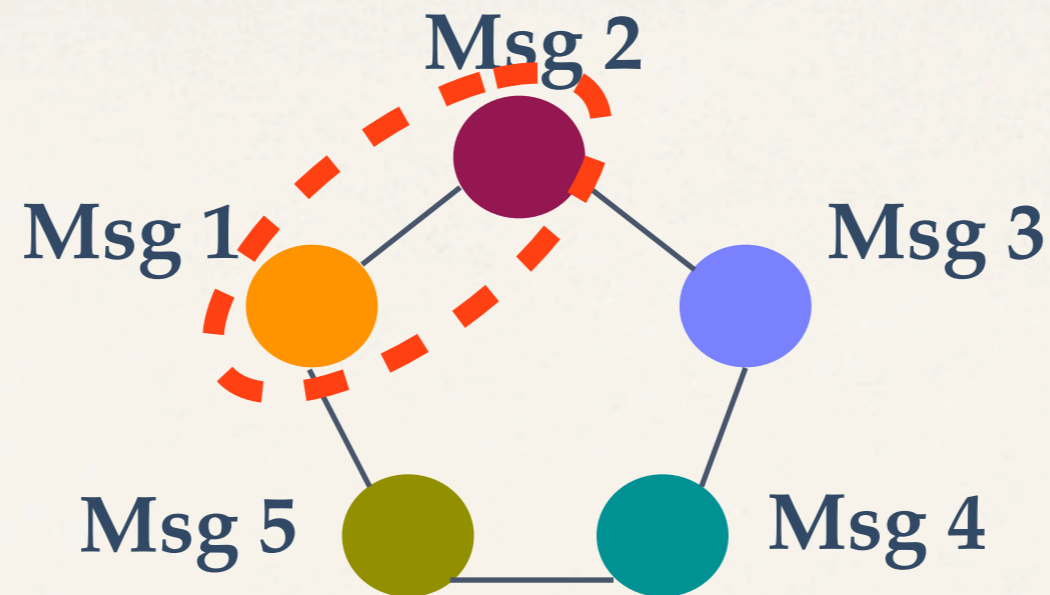
Improving communication with entanglement



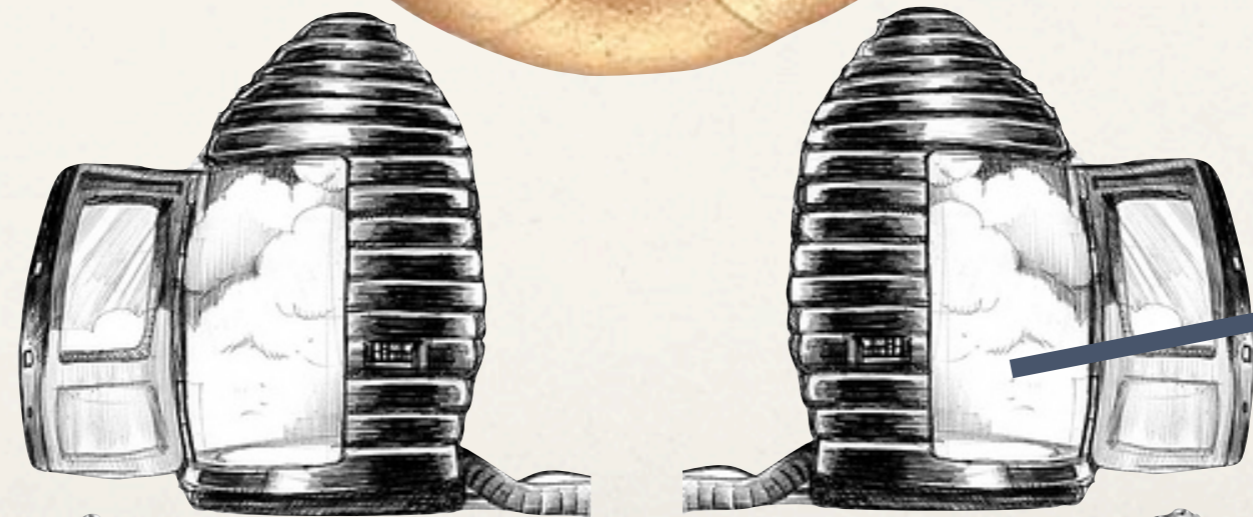
Msg 1



Improving communication with entanglement

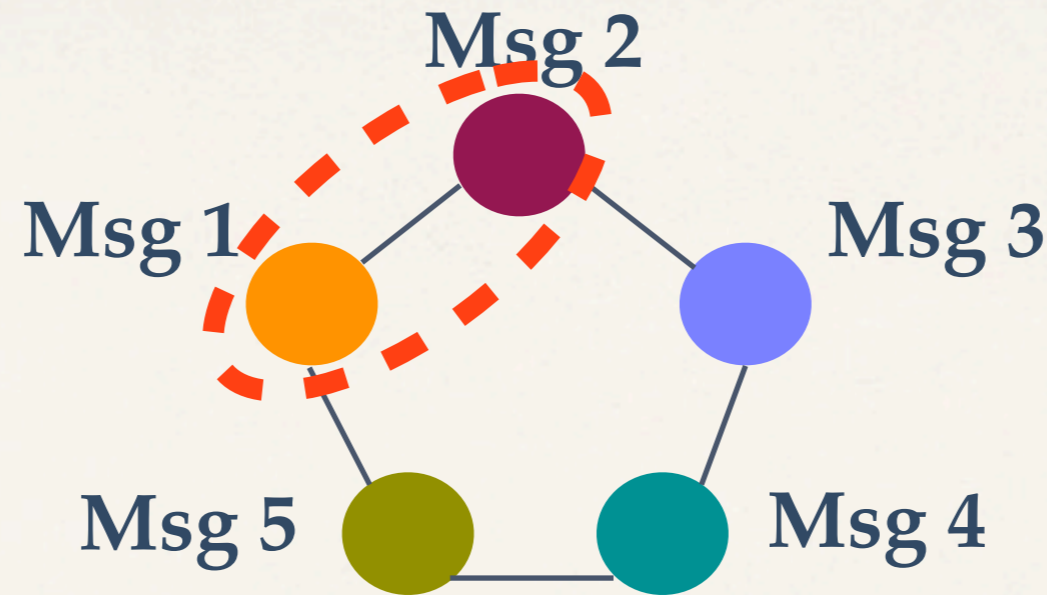


Msg 1



$v(\bullet)$

Improving communication with entanglement

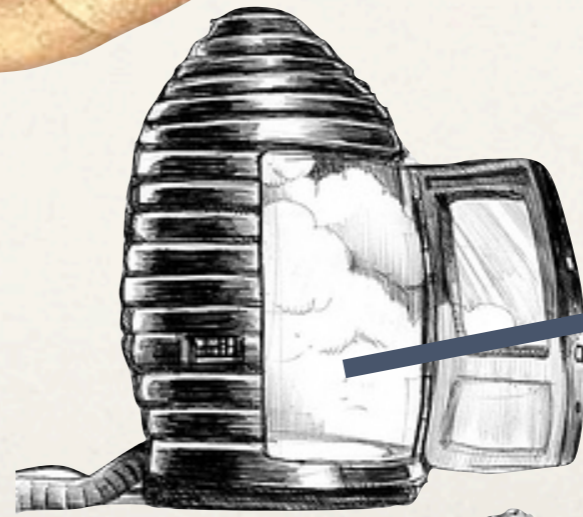
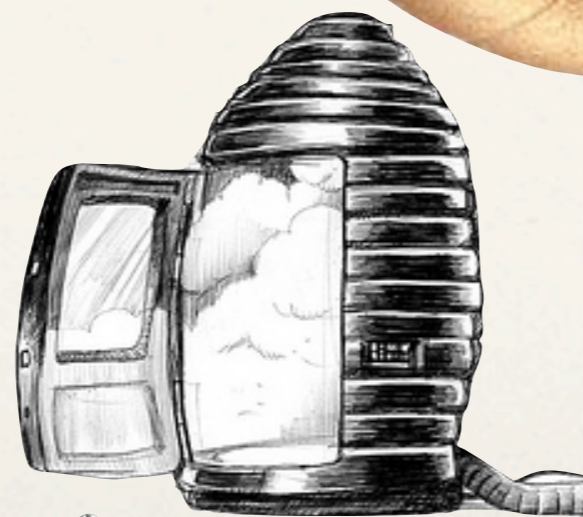


Msg 1

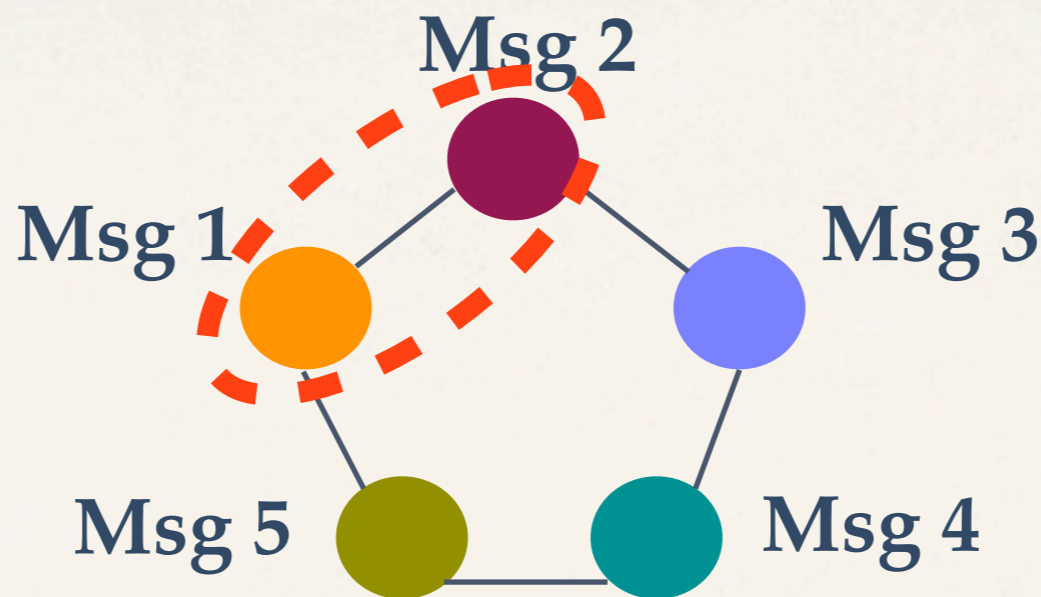


RED

90°



Improving communication with entanglement



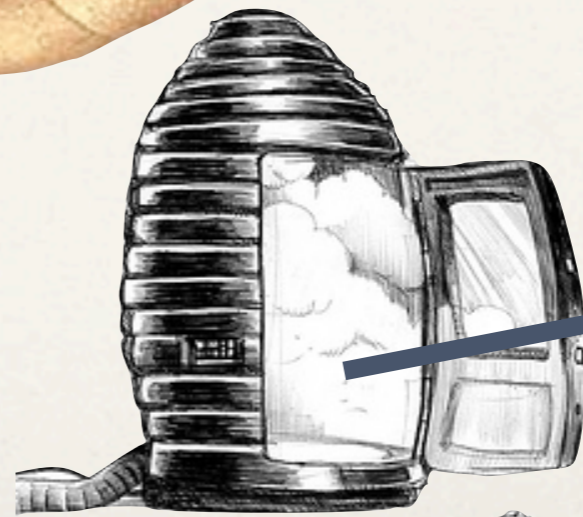
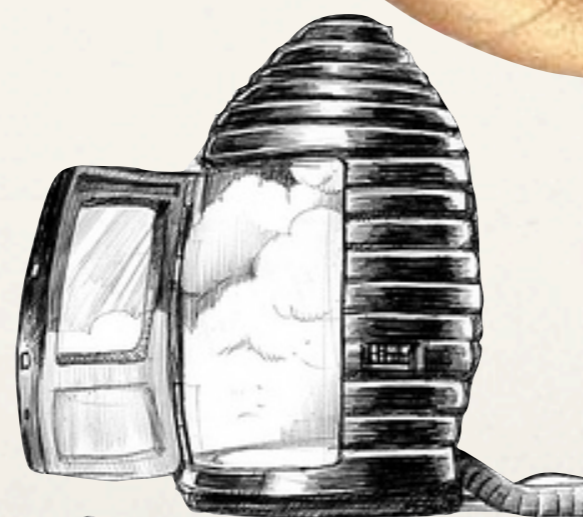
Msg 1



RED



90°



Msg 1

Improving communication with entanglement

WRAPPING UP

Improving communication with entanglement

WRAPPING UP

- ❖ If a graph has sufficiently small d and large α

Improving communication with entanglement

WRAPPING UP

- ❖ If a graph has sufficiently small d and large α
 - ❖ Then using teleportation we can improve over the (*zero-error*) Shannon capacity!

Improving communication with entanglement

WRAPPING UP

- ❖ If a graph has sufficiently small d and large α
 - ❖ Then using teleportation we can improve over the (*zero-error*) Shannon capacity!
- ❖ Our result: *unbounded improvement* using a family of Hadamard graphs

Improving communication with entanglement

WRAPPING UP

- ❖ If a graph has sufficiently small d and large α
 - ❖ Then using teleportation we can improve over the (*zero-error*) Shannon capacity!
- ❖ Our result: *unbounded improvement* using a family of Hadamard graphs
- ❖ Many links with classical graph theory (e.g. quantum independence number)

Improving communication with entanglement

WRAPPING UP

- ❖ If a graph has sufficiently small d and large α
 - ❖ Then using teleportation we can improve over the (*zero-error*) Shannon capacity!
- ❖ Our result: *unbounded improvement* using a family of Hadamard graphs
- ❖ Many links with classical graph theory (e.g. quantum independence number)

Thanks!