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## Learning

Hidden units are crucial for learning difficult tasks, to allow activity patterns to be re-represented (transformed).

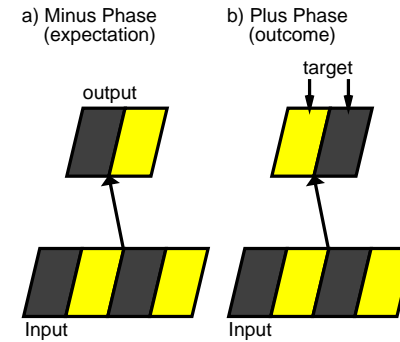
Hebbian works for learning about the world, but not for learning particular tasks.

Error-driven rule can learn tasks, using discrepancy between actual and target outputs (error).

Combination of Hebbian and error-driven learning consistent w/biology, works w/hidden units.

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## Phases



Neurons don't need to explicitly remember and compare - and + phases.

Effects through  $Ca^{2+}$ .

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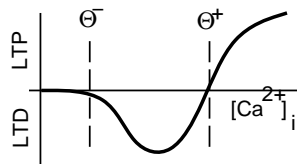
## Biological Implementation

Minus Phase	Plus Phase					
	$x_i^+, y_j^+ \approx 0$			$x_i^+, y_j^+ \approx 1$		
	Err	Hebb	Combo	Err	Hebb	Combo
$x_i^-, y_j^- \approx 0$	0	0	0	+	+	+
$x_i^-, y_j^- \approx 1$	-	0	-	0	+	+

No  $Ca^{2+}$  → no learning

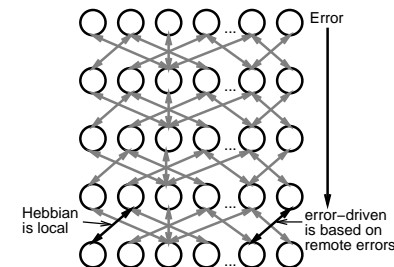
Mod  $Ca^{2+}$  → LTD

High  $Ca^{2+}$  → LTP



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## Pros and Cons of Hebbian and Error-Driven Learning



	Pro	Con
Hebbian (local)	autonomous, reliable	myopic, greedy
Error-driven (remote)	task-driven, cooperative	co-dependent, lazy

Error-driven = Left-wing, Hebbian = Right-wing

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## Combining Error-driven + Hebbian

Get benefits of both.

$$\Delta w_{ij} \approx \Delta_{hebb} + \Delta_{err} \quad (1)$$

$$\Delta_{hebb} = \epsilon a_j (a_i - w_{ij})$$

$$\Delta_{err} = \epsilon [(a_i^+ a_j^+) - (a_i^- a_j^-)]$$

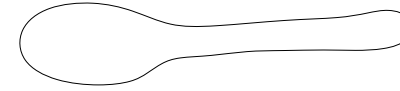
$$\Delta w_{ij} = (k_{hebb}) \Delta_{hebb} + (1 - k_{hebb}) (\Delta_{err}) \quad (2)$$

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## Generalization

How well do we deal with things we've never seen before?

nust



each time you walk into class, each social interaction, each sentence you hear, etc.

We're constantly faced with new situations, and generalize reasonably well to them.

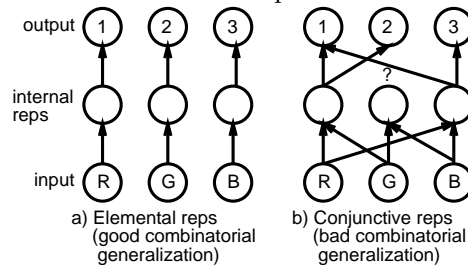
How do we do it?

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## Generalization

Distributed reps: novel items are novel combinations of existing features (combinatorial representations): "nust"

Requires elemental, combinatorial reps:



Hebbian learning & inhibitory competition constrain error-driven learning to form such reps (sims).

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## Combining Error-driven + Hebbian

Get benefits of both: Solve tasks, learn systematic representations, generalize to new stimuli.

What's left?...