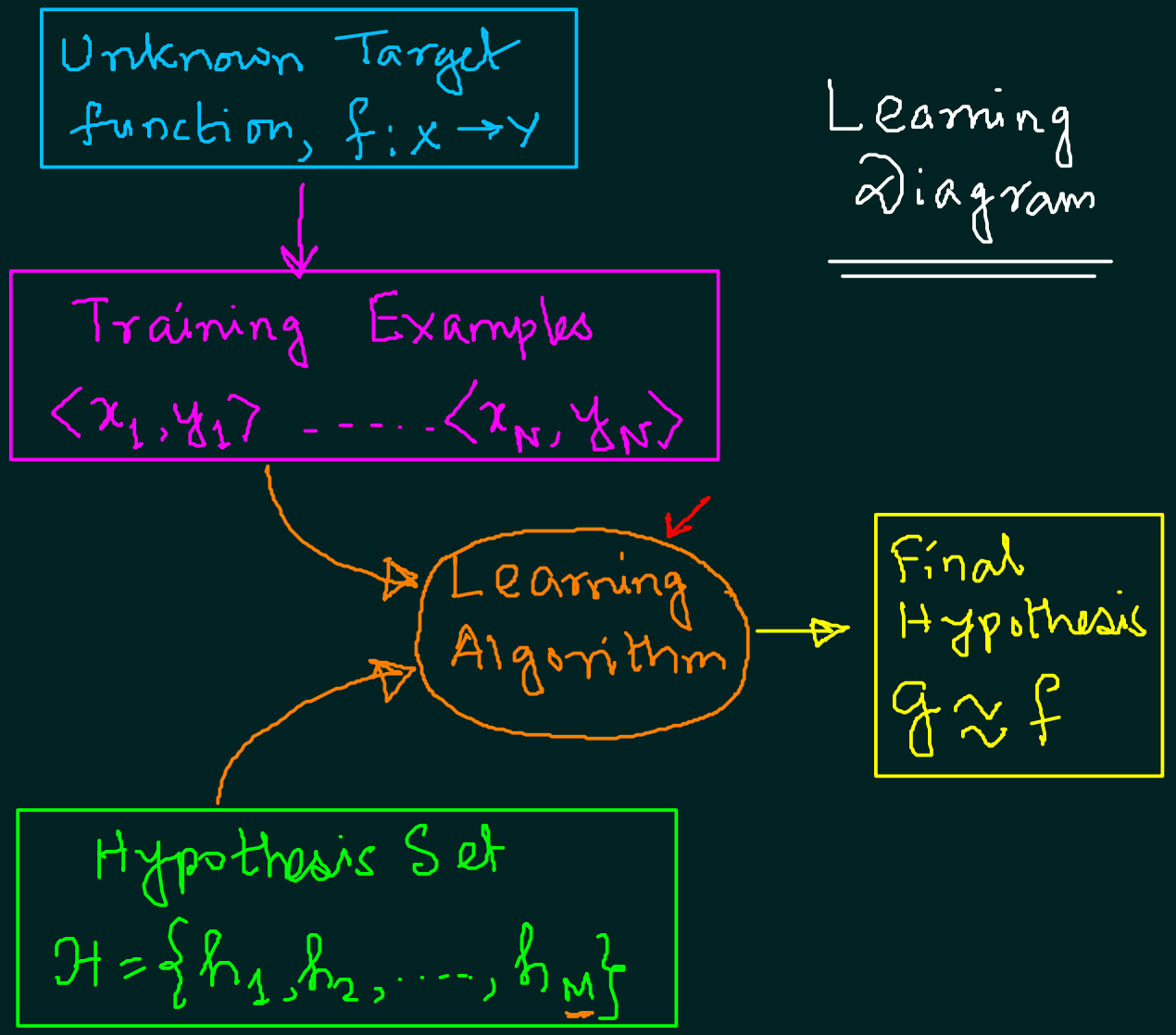


Learning diagram

- What is learning?
- When can we learn?
- Can we Really learn?
- How to learn?
- How to learn / do it well?

Path Ahead !!

- **Hoeffding Inequality:**

$$\text{Prob}\left[\,|E_{in}(g) - E_{out}(g)| > \epsilon\,\right] \leq 2Me^{-2\epsilon^2 N}$$

P.A.C.

Concept Learning

Ordering of Hypothesis :

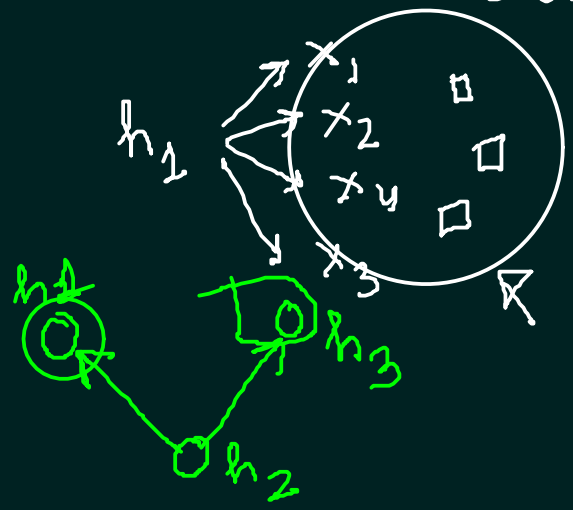
Sky	Temp	Humid	Wind	Water	Forecst	EnjoySpt
Sunny	Warm	Normal	Strong	Warm	Same	Yes
Sunny	Warm	High	Strong	Warm	Same	Yes
Rainy	Cold	High	Strong	Warm	Change	No
Sunny	Warm	High	Strong	Cool	Change	Yes

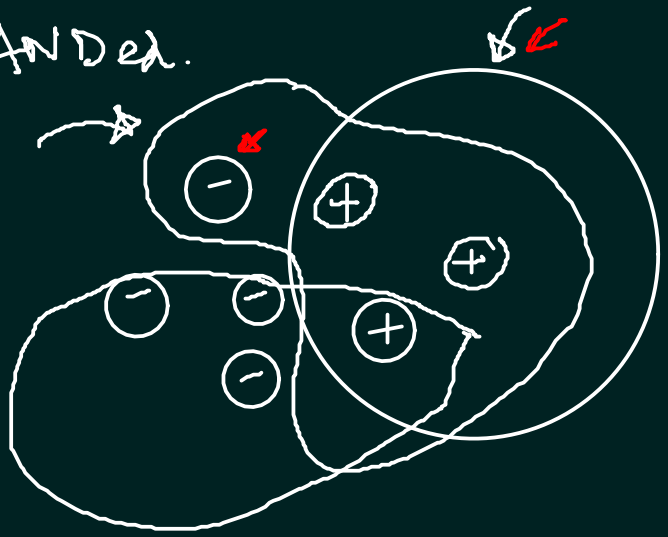
$h_1 = \langle Sunny, ?, ?, Strong, ?, ? \rangle$

$h_2 = \langle Sunny, ?, ?, ?, ?, ? \rangle$

$h_3 = \langle Sunny, ?, ?, ?, Cool, ? \rangle$

Boolean functions → ANDed.



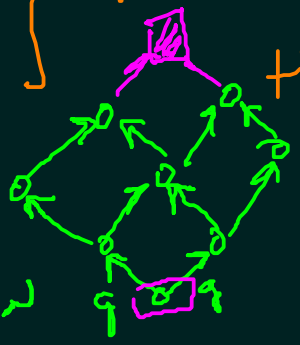


$\langle Sunny, ?, ?, Strong, Cool, ? \rangle$

$h_2 \geq_g h_1$

$h_2 \geq_g h_3$

more general than



Partial order

$h_1 \geq_s h_2$

$h_3 \geq_s h_2$

$h_1 \not\geq_{g/s} h_3$

$G = \langle ? \; ? \; ? \; ? \; ? \; ? \rangle$

$S = \langle \emptyset \; \emptyset \; \emptyset \; \emptyset \; \emptyset \; \emptyset \rangle$

Concept Learning (C TARGET)

↳ Boolean functions

Sky	Temp	Humid	Wind	Water	Forecst	EnjoySpt
Sunny	Warm	Normal	Strong	Warm	Same	= Yes
Sunny	Warm	High	Strong	Warm	Same	Yes
Rainy	Cold	High	Strong	Warm	Change	= No
Sunny	Warm	High	Strong	Cool	Change	Yes

Training Example (TE)

$h \approx c \rightarrow (\text{Sky} = \text{Sunny}) \wedge (\text{Humid} = \text{High})$

$H = [h_1, h_2, h_3, \ldots, h_M]$

$h_1 = \langle \text{Sunny}, ?, \text{High}, ?, ?, ? \rangle$

$h_2 = \langle \text{Rainy}, ?, ?, \emptyset, ?, \text{Cool}, ? \rangle$

$h_3 = \ldots$

? → anything (TRUE)

$\emptyset$ → nothing (FALSE)

Only 4 TEs

▷ Goal: $\forall x \in X, \; h(x) = c(x)$

▷ Search Problem: $\text{Sky} = \{\text{Sunny}, \text{Rainy}, \text{Cloudy}\} \Rightarrow |\text{Sky}| = 3$

$|\text{Temp}| = |\text{Humid}| = |\text{Wind}| = |\text{Water}| = |\text{Forecast}| = 2$

Instances $= 3 \times 2 \times 2 \times 2 \times 2 \times 2 = 96 \rightarrow 2^{96}$ Hypothesis all together!

Hypothesis (our Restriction) $= (3+2) \times (2+2) \times (2+2) \times (2+2) \times (2+2) \times (2+2) = 5120$

↳ Actual Possible Hypothesis $= 4 \times 3 \times 3 \times 3 \times 3 \times 3 + 1 = 973$

Concept Learning:

↳ Inductive Learning Hypothesis Assumption

Sky	Temp	Humid	Wind	Water	Forecst	EnjoySpt
Sunny	Warm	Normal	Strong	Warm	Same	Yes
Sunny	Warm	High	Strong	Warm	Same	~~Yes~~ No
Rainy	Cold	High	Strong	Warm	Change	No
Sunny	Warm	High	Strong	Cool	Change	Yes

⇒ Hypothesis Constructed from Training Data → Approx. Test Data / Unknown f well

↳ Hypothesis Set

Training Data (TE) ↓ Learn Boolean function

▶ Find-S Algorithm:

↳ Take +ve Examples only

↳ Start from h^S and Relax

$\langle \phi, \phi, \phi, \phi, \phi, \phi \rangle$

TE_1: ⟨Sunny, Warm, Normal, Strong, Warm, Same⟩

TE_2: ⟨Sunny, Warm, ?, Strong, Warm, Same⟩

TE_3: DO NOTHING

TE_4: ⟨Sunny, Warm, ?, Strong, ?, ?⟩ ← Answer

▶ Most Specific Hypothesis

$h^S = \langle \phi, \phi, \phi, \phi, \phi, \phi \rangle$

▶ Most General Hypothesis

$h^G = \langle ?, ?, ?, ?, ?, ? \rangle$

▶ NOTE:

(1) Correctness

(2) TE Noise ✓

(3) Why most specific?

(4) Multiple Hyp??

Version Space :

S : < Sunny, Warm, ?, Strong, ?, ? >

Sky	Temp	Humid	Wind	Water	Forecst	EnjoySpt
Sunny	Warm	Normal	Strong	Warm	Same	Yes = f(x)
Sunny	Warm	High	Strong	Warm	Same	Yes
Rainy	Cold	High	Strong	Warm	Change	No
Sunny	Warm	High	Strong	Cool	Change	Yes

< Sunny, ?, ?, Strong, ?, ? > < Sunny Warm, ?, ?, ?, ? > < ?, Warm, ?, Strong, ?, ? >

G : < Sunny, ?, ?, ?, ?, ? > < ?, Warm, ?, ?, ?, ? >

- Consistent $(h, \mathcal{D}) = \forall \langle x, f(x) \rangle \in \mathcal{D} \; [h(x) = f(x)]$
- Version Space, $VS_{\mathcal{H},\mathcal{D}} = \{ h \in \mathcal{H} \mid \text{consistent}(h, D) \}$
- General Boundary, $G = \{ g \in \mathcal{H} \mid \text{consistent}(g, \mathcal{D}) \wedge \neg \exists g' \, [g' >_g g) \wedge \text{consistent}(g', \mathcal{D}) \}$
- Specific Boundary, $S = \{ s \in \mathcal{H} \mid \text{consistent}(s, \mathcal{D}) \wedge \neg \exists s' , (s >_g s') \wedge \text{consistent}(s', \mathcal{D}) \}$

— List-And-Eliminate —

Candidate Elimination Algorithm :

Sky	Temp	Humid	Wind	Water	Forecst	EnjoySpt
Sunny	Warm	Normal	Strong	Warm	Same	Yes
Sunny	Warm	High	Strong	Warm	Same	Yes
Rainy	Cold	High	Strong	Warm	Change	No
Sunny	Warm	High	Strong	Cool	Change	Yes

$S : \langle \phi, \phi, \phi, \phi, \phi, \phi \rangle$

$S_1 : \langle Sunny, Warm, Normal, Strong, Warm, Same \rangle$

$S_2 : \langle Sunny, Warm, ?, Strong, Warm, Same \rangle$ ← S_3

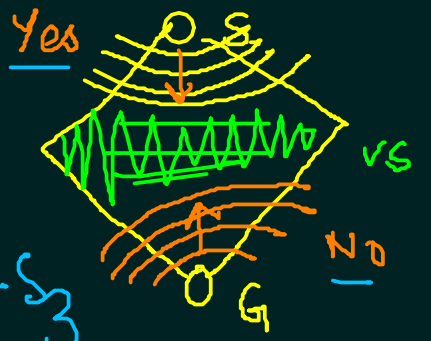
$S_4 : \langle Sunny, Warm, ?, Strong, ?, ? \rangle$

$\langle Sunny, ?, Strong, ?, ? \rangle$ $\langle Sunny, Warm, ?, ?, ? \rangle$ $\langle ?, Warm, ?, Strong, ?, ? \rangle$

$G_4 : \langle Sunny, ?, ?, ?, ?, ? \rangle$, $\langle ?, Warm, ?, ?, ?, ? \rangle$

$\langle Sunny, ?, ?, ?, ?, ? \rangle$ $\langle ?, Warm, ?, ?, ?, ? \rangle$ $\langle ?, ?, ?, ?, ?, Same \rangle$: G_3, G_4

$G : \langle ?, ?, ?, ?, ?, ? \rangle$ ← G_1, G_2



VS

Sky	Temp	Humid	Wind	Water	Forecst	EnjoySpt
Sunny	Warm	Normal	Strong	Warm	Same	Yes
Sunny	Warm	High	Strong	Warm	Same	Yes
Rainy	Cold	High	Strong	Warm	Change	No
Sunny	Warm	High	Strong	Cool	Change	Yes

S: <Sunny, Warm, ?, Strong, ?, ?>

<Sunny, ?, ?, Strong, ?, ?>

<Sunny, Warm, ?, ?, ?>

<?, Warm, ?, Str, ?, ?>

G: <Sunny, ?, ?, ?, ?, ?>

<?, Warm, ?, ?, ?, ?>

▷ Correct? — Converge

what if TE error?

Wrong Hyp ∈ VS

Correct Hyp. ∉ VS

▷ If Test Data available

↳ Accuracy — 50%

Test: [<Sunny, Warm, Normal, Light, Warm, Same>] → +ve Yes

Train

|D| ← data

3⊕ 3⊖

next? TE

$\lceil \log_2 |VS| \rceil$

TE

n attributes → 2 values → Concepts → 2^{2^n} Hyp.

#Inst = 2 × 2 × ..... (n times)

↑?

▷ Restriction: < c ∧ b ∧ a ∧ d) ← Hyp ← $3^n + 1$

↳ [Inductive Bias]

Sun	Wrm	Nor	Strong	Col	Change	Yes
Cloudy	"	"	"	"	"	Yes
Rainy	"	"	"	"	"	NO

Gen

CElim

H → ∅

↳ < ? ∧ Wrm ∧ Nor ∧ Str ∧ Col ∧ Chg > X

X [< Sun ? ? ? ? > V < Cloudy , ? ? ? ? ? >]

↓ Yes

↑ No

x_1 → Yes

x_2 → Yes

x_3 → Yes

x_4 → No

x_5 → No

S: (x_4 V x_2 V x_3) ← Gen

{ |||||||||| }

G: (¬ (x_4 V x_5))

Puzzle : 3 TE , 1 TE

⇒ ONLINE vs BATCH (Next)

Season	Weather	Play Football
Summer	Rain	Yes
Winter	Dry	Yes
Winter	Rain	NO

TE

TEST: <Summer, Dry> → ?

What can M/c learn from 1 TE?

(vs Human)

Ref: (ML Book) Tom Mitchell (2nd Chap)