

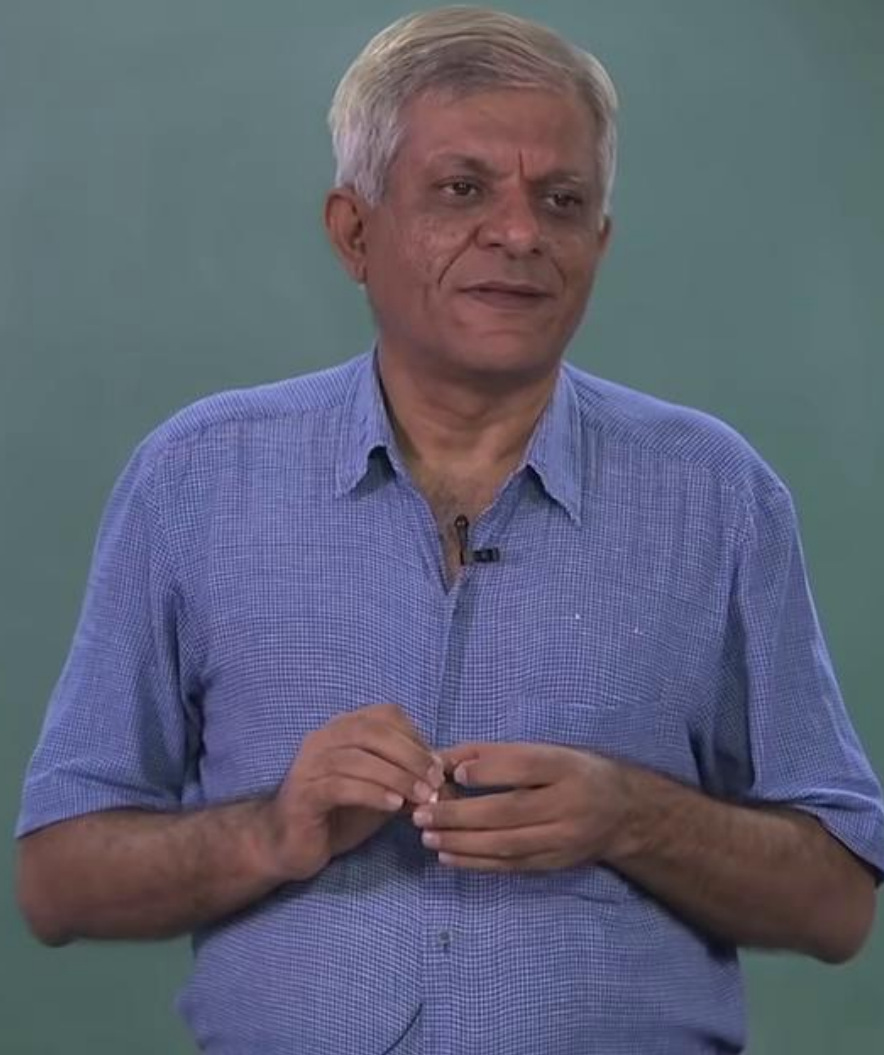
Video Lectures On Artificial Intelligence

Lecture 15 Optimization II (Genetic Algorithms)

Prof. Deepak Khemani
Department of Computer Science
IIT Madras



OPTIMIZATION



Steve Grand - CREATION

Steve Grand - CREATION

Steve Grand - CREATION
CREATURES

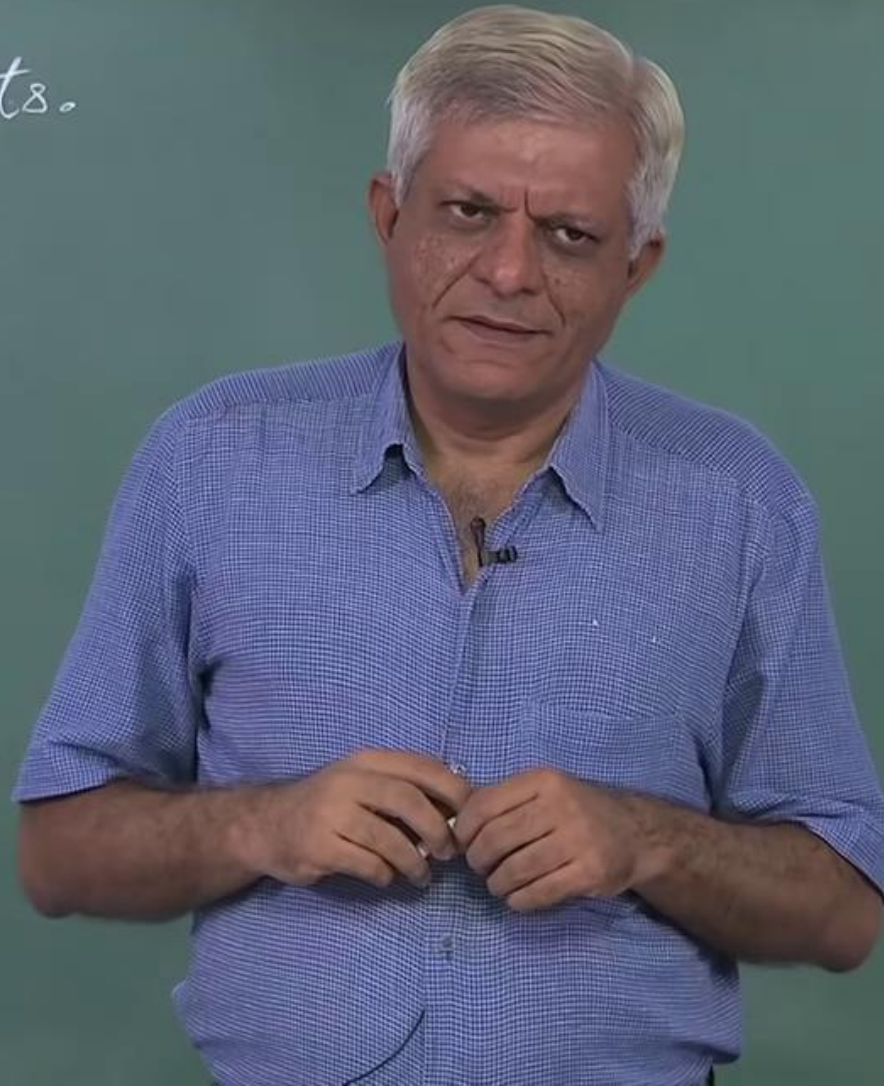


we Grand - CREATION

↓ CREATURES

whatever persists, persists.

OPTIMIZATION



Steve Grand - CREATION

↓ CREATURES

Whatever persists, persists.

OPTIMIZATION



NPTEL

Nature
↓
creating designs for life

Steve Grand - CREATION
↓
CREATURES
(whoever persists), persists.
compete

OPTIMIZATION

Nature
↓
creating designs for (life) (whatever persists), persists.
Steve Grand - CREATION
↓
CREATURES
OPTIMIZATION
compete for limited resources

Nature

↓
many designs for

species

Life forms

Steve Grand - CREATION

↓ CREATURES

Whatever perrists, perrists.

OPTIMIZATION

compete for limited resources



NPTEL

Nature

↓
creating designs for life forms

↓
"generate and test"

species

Steve Grand - CREATION

↓ CREATURES

What (s), persists.

Com. limited resources

OPTIMIZATION

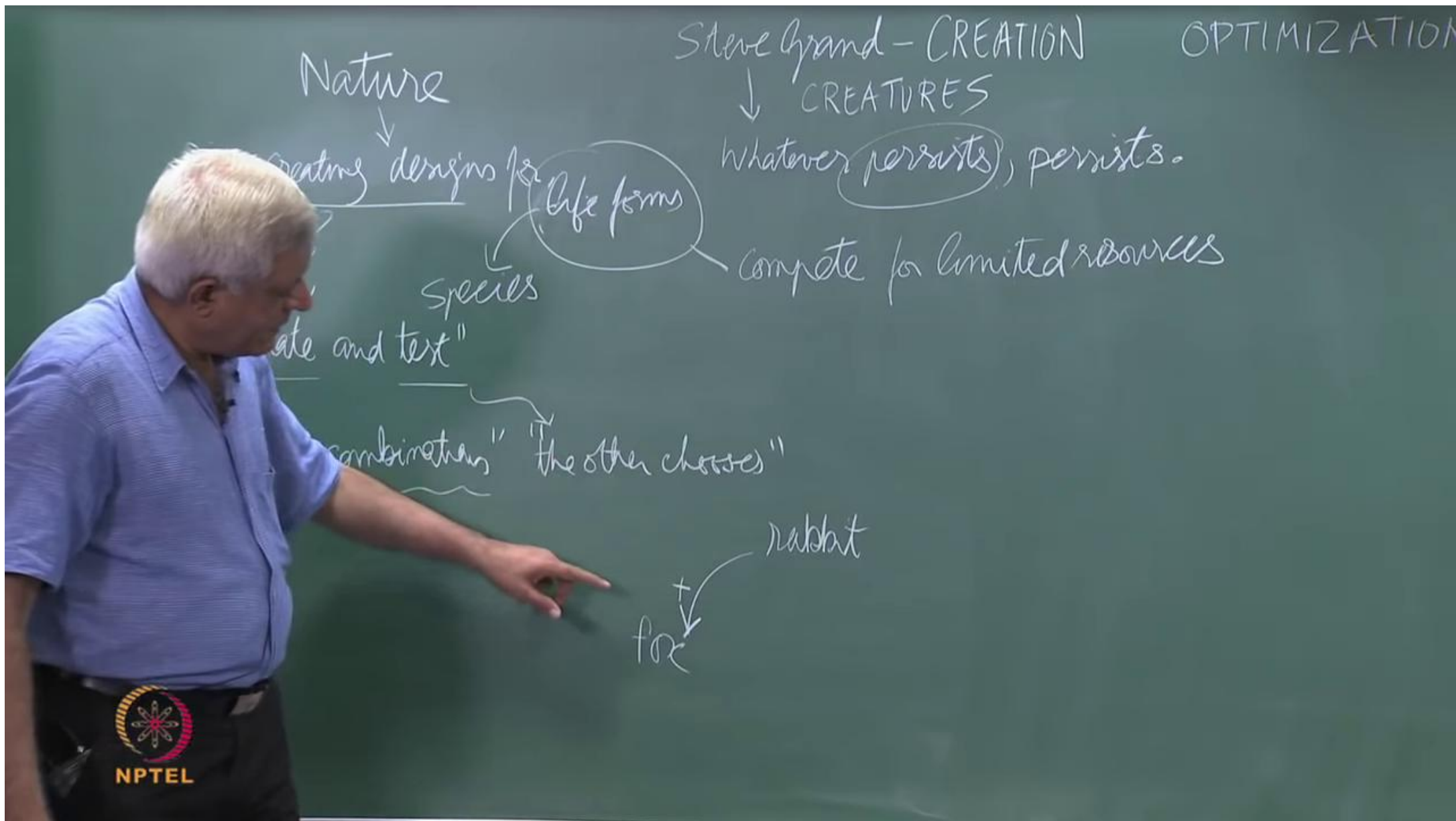


Species

↓
"generate and test"

"one makes up combinations" → "the other chooses"





Nature

creating designs for

Life forms

species

ate and test"

"combinations"

"the other chooses"

compete for limited resources

Steve Grand - CREATION

↓ CREATURES

Whatever persists, persists.

OPTIMIZATION

rabbit

fox



NPTEL

for rabbit

A hand-drawn diagram on a chalkboard. The word "for" is written in cursive on the left, and "rabbit" is written in cursive on the right. A curved arrow points from "for" to "rabbit". Above this arrow, there is a small cross symbol (+) and a downward-pointing arrow, indicating a positive feedback loop.

Nature

creating designs for life forms

species
and test"

"the other choices"

Steve Grand - CREATION

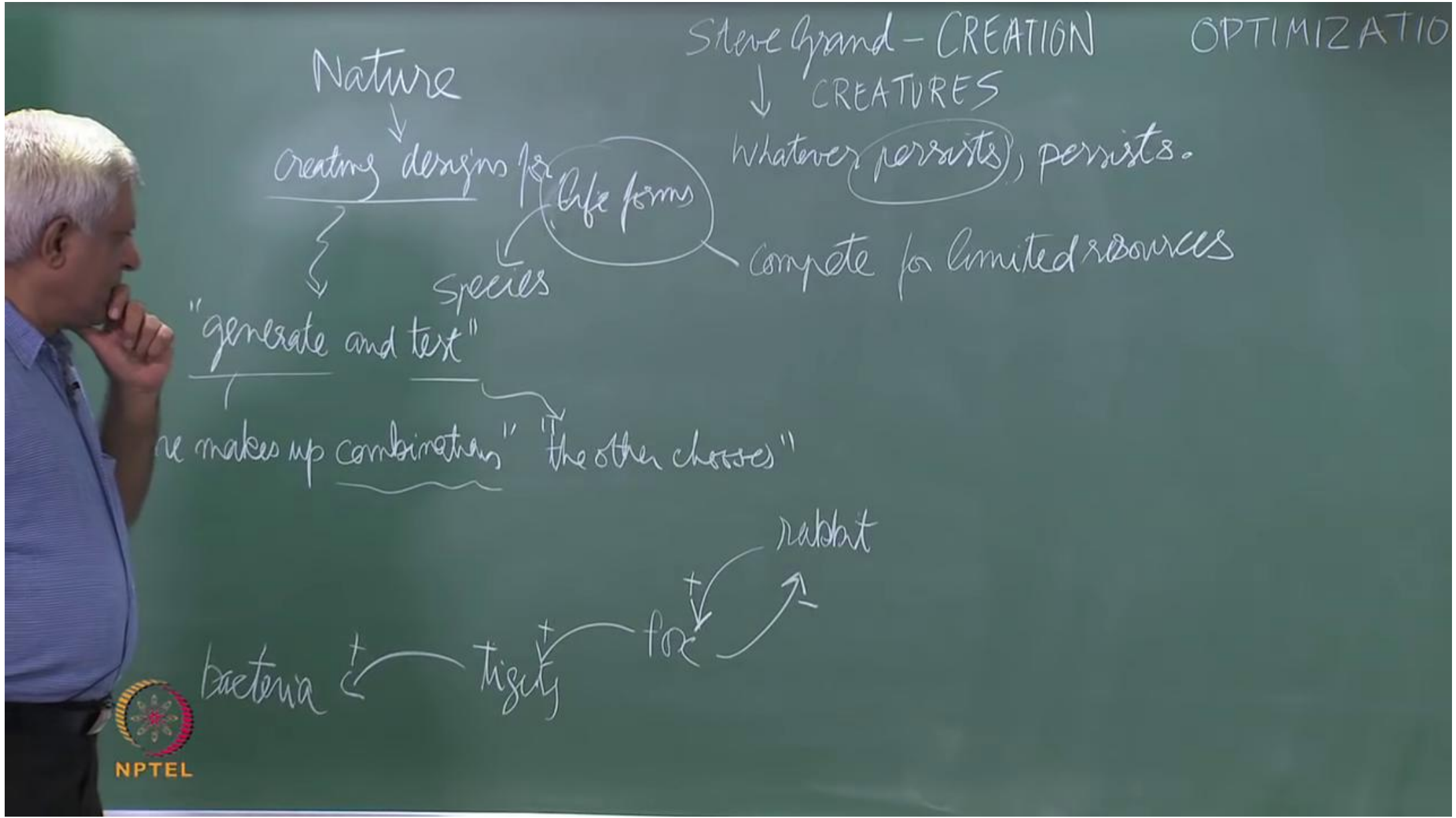
↓ CREATURES

Whatever persists, persists.

compete for limited resources

OPTIMIZE





Nature

creating designs for life forms



species

"generate and test"

one makes up combinations "the other chooses"

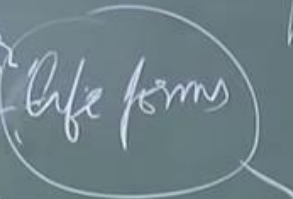
Steve Grand - CREATION

↓ CREATURES

whatever persists, persists.

OPTIMIZATION

compete for limited resources



Nature

Steve Grand - CREATION

OPTIMIZATION

CREATURES

Whatever persists, persists.

Life forms

Species

Compete for limited resources

between species

within the species

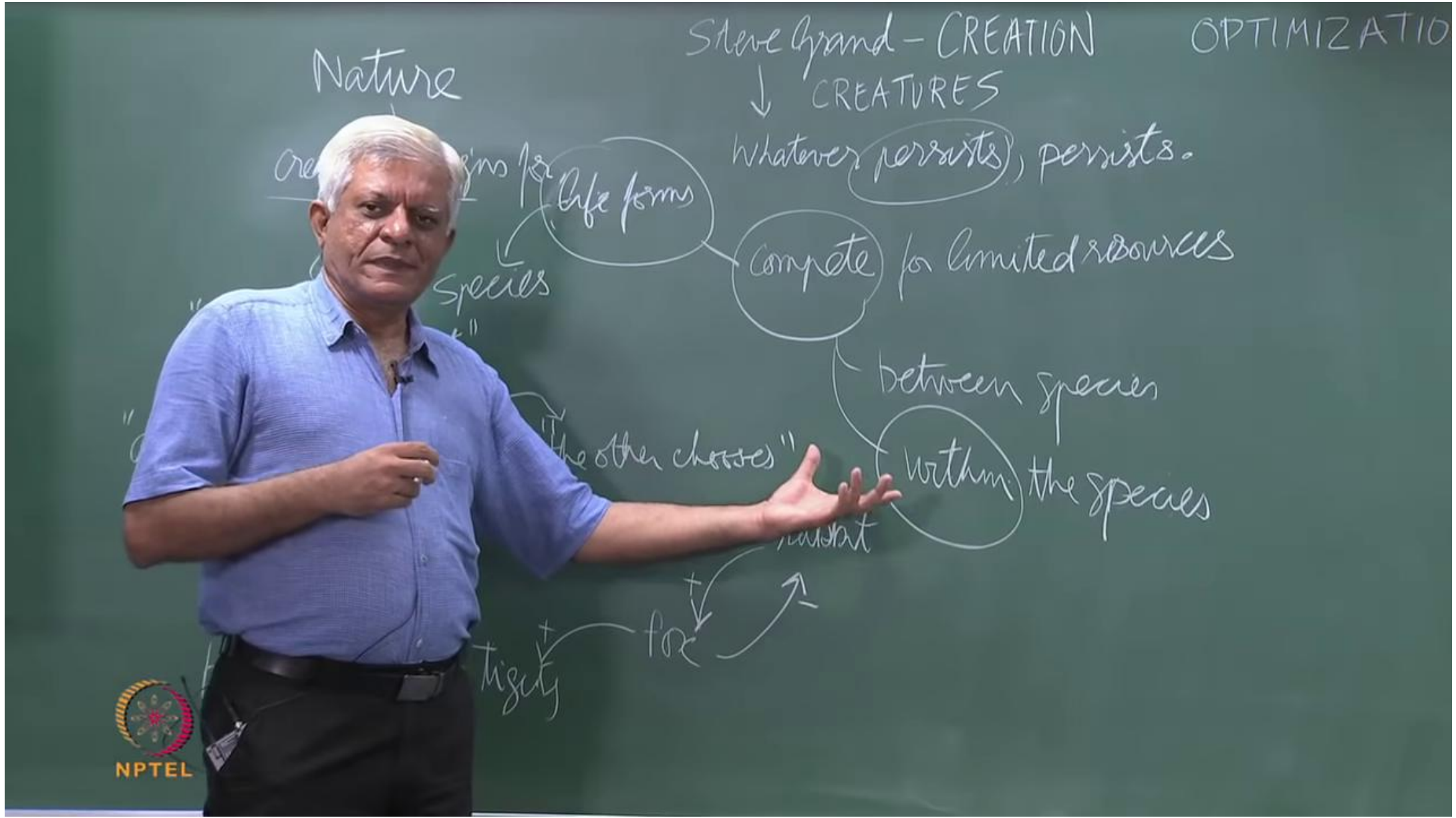
"the other chooses"

fox

rabbit

tiger

NPTEL



Nature

Steve Grand - CREATION

OPTIMIZATION

CREATURES

Whatever persists, persists.

Life forms

Species

Compete for limited resources

between species

within the species

"The other chooses"

tiger

fox

predator



Nature

Steve Grand - CREATION OPTIMIZATION

↓ CREATURES

Whatever persists, persists.

creating designs for Life forms

species

compete for limited resources

"generate and test"

"makes up combinations" "the other chooses"

reproduction → Genetic mixing

between species

within the species

bacteria + tiger + fox + rabbit

The chalkboard contains the following handwritten content:

- Top Left:** "Nature" with an arrow pointing down to "creating designs for".
- Top Right:** "Steve Grand - CREATION OPTIMIZATION" with an arrow pointing down to "CREATURES". Below this is "Whatever persists, persists." where "persists" is circled.
- Center:** A flow diagram starting with "Life forms" (circled), leading to "species", then "compete for limited resources" (circled). From "compete", two arrows point down to "between species" and "within the species", both of which are circled.
- Left Side:** "creating designs for" has a lightning bolt symbol leading to "generate and test" (underlined). Below this is "makes up combinations" (underlined) and "the other chooses" (underlined). An arrow points from "makes up combinations" to "reproduction", which then points to a box labeled "Genetic mixing".
- Bottom:** A food chain diagram: "bacteria" has an arrow pointing to "tiger" (with a "+" sign), "tiger" has an arrow pointing to "fox" (with a "+" sign), and "fox" has an arrow pointing to "rabbit" (with a "+" sign).

Nature

creating designs for life forms

species

"generate and test"

"makes up combinations" "the other chooses"

GENOTYPE

reduction → Genetic mixing

competition

between species

within the species

Survival of the fittest - CREATION

↓ CREATURES

Whatever persists, persists.

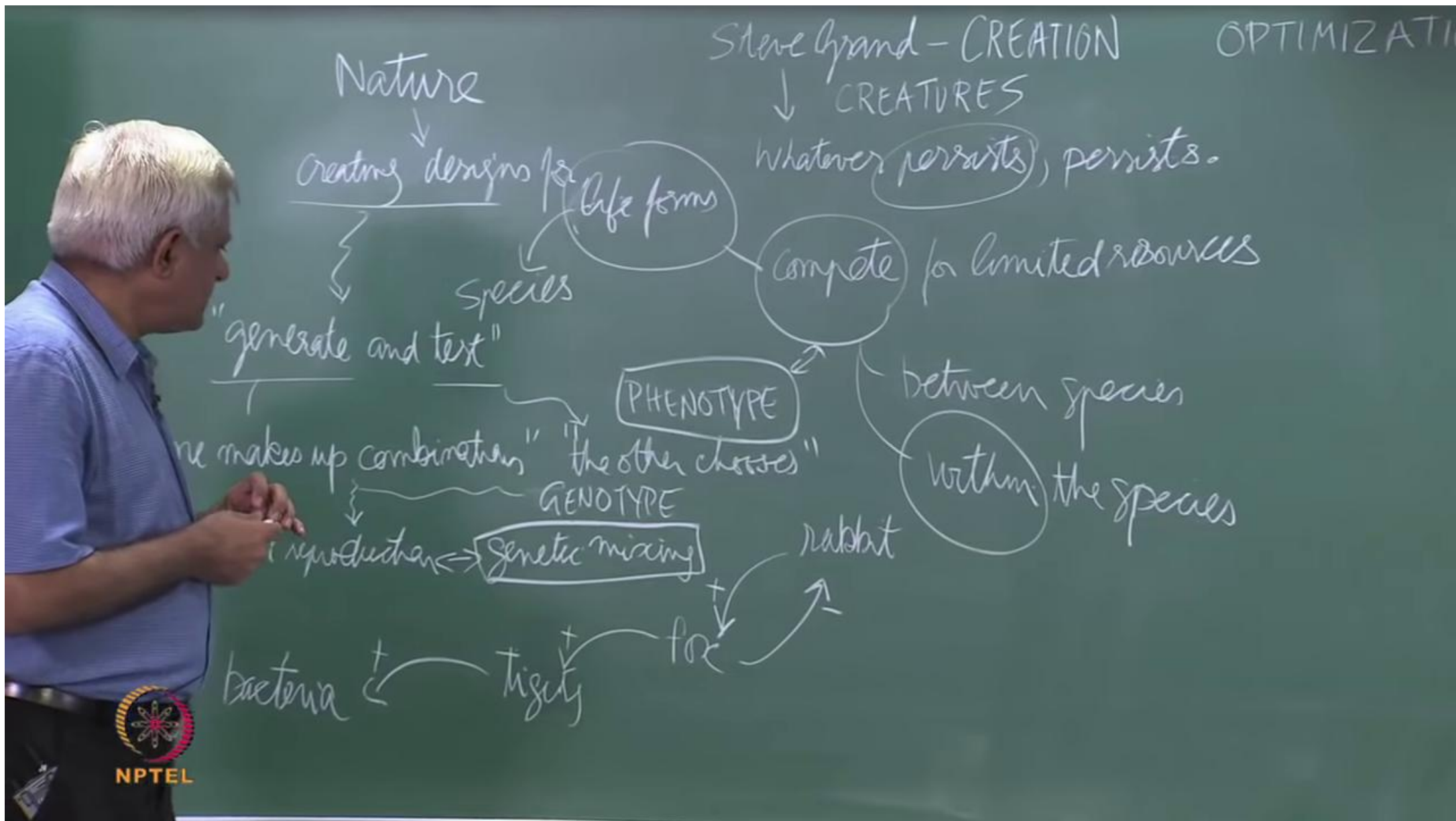
bacteria

tiger

fox

rabbit

NPTEL



Nature

Steve Grand - CREATION

↓ CREATURES

Whatever persists, persists.

OPTIMIZATION

Life forms

Compete for limited resources

between species

within the species

PHENOTYPE

"then chooses"

fox

rabbit

EMERGENT BEHAVIOUR

The chalkboard contains the following handwritten text and diagrams:

- Top Left:** "Nature" with a small arrow pointing down.
- Top Center:** "Steve Grand - CREATION" followed by "↓ CREATURES".
- Top Right:** "OPTIMIZATION".
- Center:** "Whatever persists, persists." with "persists" circled.
- Left Side:** "Life forms" circled, with "Creatures" written above it and "ties" below it. A lightning bolt symbol is drawn next to "Creatures".
- Center-Right:** "Compete for limited resources" circled.
- Below Center:** "PHENOTYPE" circled, with "then chooses" written below it.
- Bottom Left:** A diagram showing a "fox" with a "+" sign and an arrow pointing to a "rabbit".
- Bottom Right:** "EMERGENT BEHAVIOUR" with an arrow pointing down to it from the "within the species" circle.
- Bottom Left Corner:** NPTEL logo.

Nature

Steve Grand - CREATION

OPTIMIZATION

↓ CREATURES

Whatever persists, persists.

Life forms

Compete for limited resources

species

"test"

PHENOTYPE

between species

within the species

GENOTYPE

genetic mixing

rabbit

fox

tiger

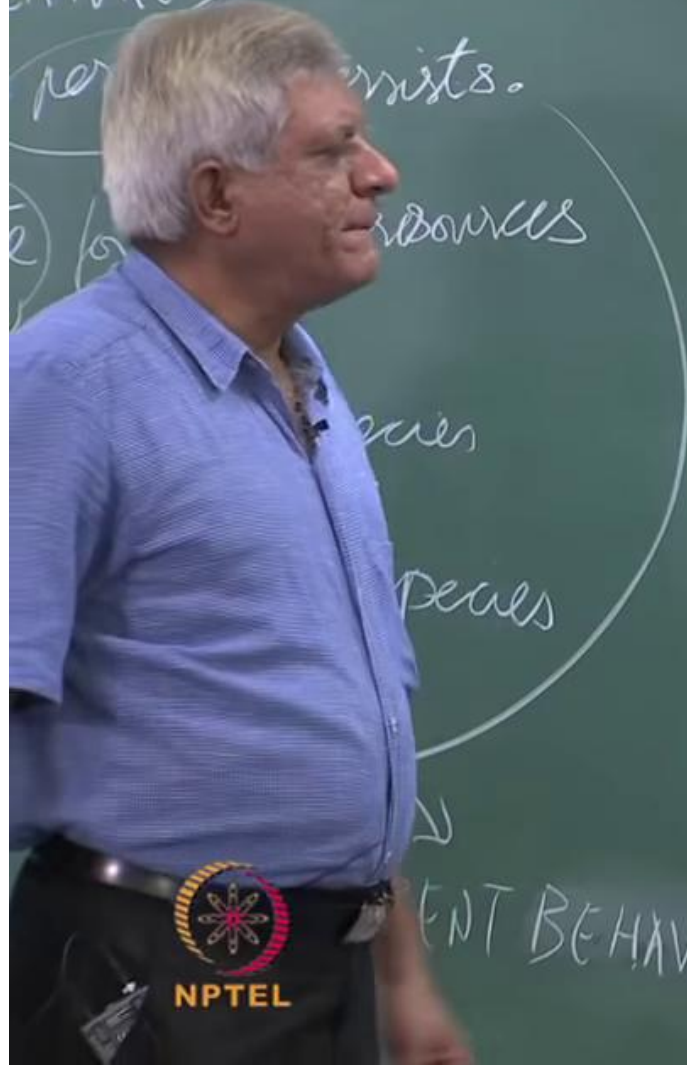
EMERGENT BEHAVIOUR



and - CREATION
FEATURES

OPTIMIZATION

→ GENETIC ALGORITHMS (GAs)



and - CREATION
FEATURES

or persists), persists.

for limited resource

between species

within the

but

OPTIMIZATION

GENETIC ALGORITHMS (GAs)

John Holland

David Goldberg



ATION → GENETIC ALGORITHMS (GAs)
↓
work with populations of
↳ John Holland.
David Goldberg → book

TION → GENETIC ALGORITHMS (GAs)

↓

Work with populations of candidates

→ John Holland

David Goldberg → book

OPTIMIZATION

→ GENETIC ALGORITHMS (GAs)

Work with population
Candidates

→ John Holland

David Goldberg → book

Encode solution as a string

Chromosome



NT BEHAVIOUR

ON → GENETIC ALGORITHMS (GAs)

Work with populations of Candidates

→ John Holland

David Goldberg → book

— encode solution as a string

← Chromosome

ION → GENETIC ALGORITHMS (GAs)

- Work with populations of candidates $P(1) \dots P(n)$
- John Holland
- David Goldberg → book
- ① Encode solution as a string
 - ② Fitness function $f(n)$
 \parallel
 $eval(n)$
 \parallel
 $h(n)$
- Chromosome

GENETIC ALGORITHMS (GAs)

John Holland.
David Goldberg → book
encode solution as a string
Chromosome

② Fitness function $f(n)$
eval(n)
 $h(n)$

GA
① SELECTION & fitness

P_1
 P_2
 P_3
⋮
 P_n

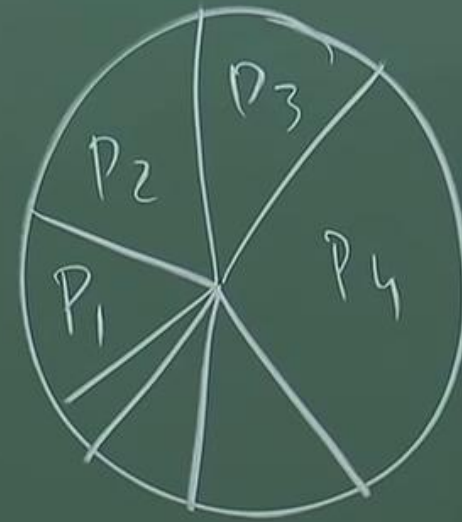
WA

① SELECTION \propto fitness

P_1
 P_2
 P_3

...

P_n

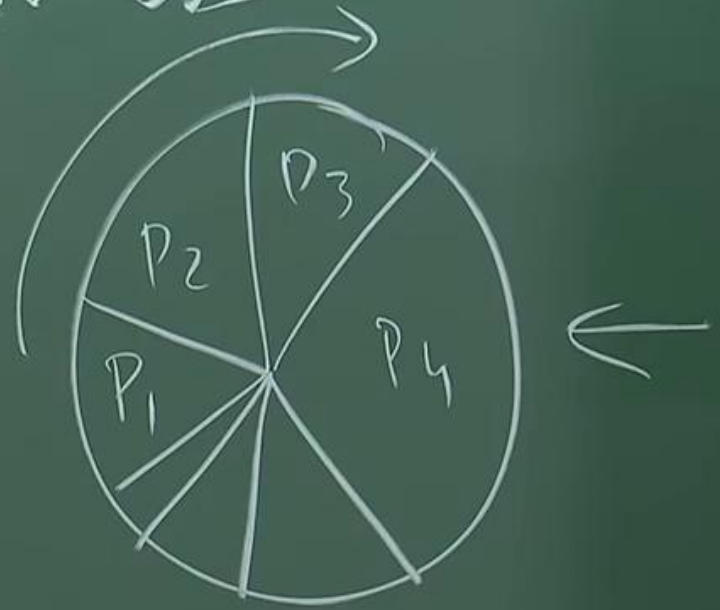


GA

① SELECTION & fitness

P_1
 P_2
 P_3
⋮
 P_n

P_1'
 P_2'
⋮
 P_n'



ALGORITHMS (GAs)

John Holland
David Goldberg → book
① encode as a string
genome
fitness function

GA

① SELECTION \propto fitness

P_1
 P_2
 P_3
⋮
 P_n

→

P'_1
 P'_2
⋮
 P'_n



② CROSSOVER

ALGORITHMS (GAs)

thousands of iterations
dates
① encode solution as a string
fitness function

Goldberg

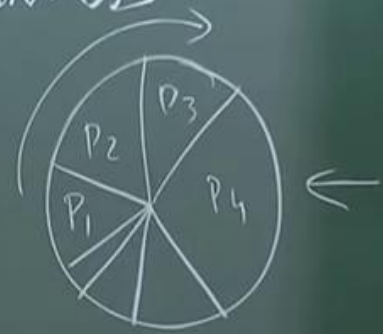
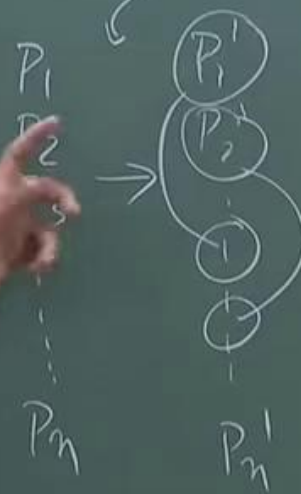
→ book

Chromosome

Chromosome

GA

① SELECTION & fitness



② CROSSOVER



NPTEL

GENETIC ALGORITHMS (GAs)

John Holland

David Fogel

book

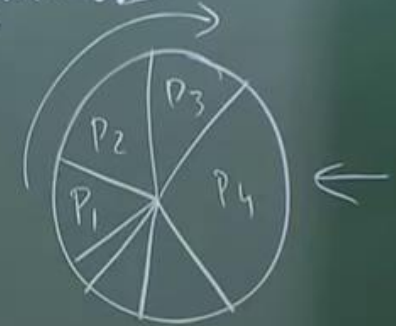
relations of
candidates

① encode solution as a string
fitness function

GA

① SELECTION & fitness

P_1
 P_2
 P_3
...
 P_n



② CROSSOVER

$$P_1 = X_1 X_2 X_3 X_4 X_5 X_6 X_7 X_8 X_9$$

GENETIC ALGORITHMS (GAs)

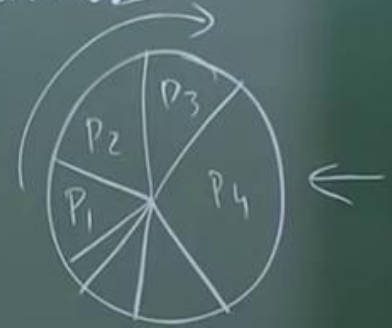
John Holland.
David Goldberg → book
code solution as a string
Chromosome

$f(n)$
 $g(n)$
 $h(n)$

GA

① SELECTION & fitness

P_1
 P_2
 P_3
...
 P_n



② CROSSOVER

$P_0 = X_1 X_2 X_3 X_4 X_5 X_6 X_7 X_8 X_9$
 $P_1 = Y_1 Y_2 Y_3 Y_4 \dots Y_9$

② CROSSOVER

$$P_1 = X_1 X_2 X_3 X_4 \mid X_5 X_7 X_8 X_9$$

$$P_2 = Y_1 Y_2 Y_3 Y_4 \mid \dots Y_9$$

$$C_1 = X_1 X_2 X_3 X_4 Y_5 Y_6 \dots Y_9$$

$$C_2 = Y_1 \dots Y_4 X_5 \dots X_9$$



GENETIC ALGORITHMS (GAs)

John Holland

David Goldberg → book

encode solution as a string

fitness $f(n)$
 evaluation $eval(n)$
 mutation $M(n)$

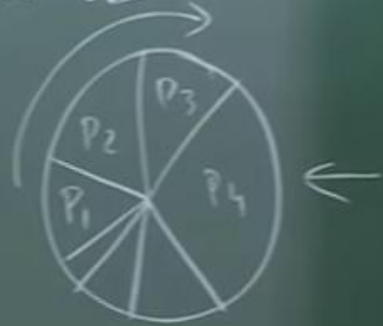
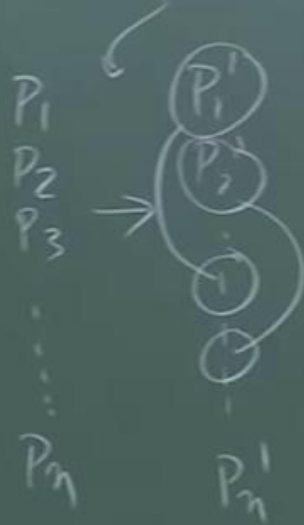
Chromosome

$$C_1 = X_1 X_2 X_3 X_4 Y_5 Y_6 Y_7 Y_8 Y_9$$

$$C_2 = Y_1 Y_2 Y_3 Y_4 X_5 X_6 X_7 X_8 X_9$$

GA

① SELECTION & fitness



② CROSSOVER

$$P_1 = X_1 X_2 X_3 X_4 | Y_5 X_6 X_7 X_8 X_9$$

$$P_2 = Y_1 Y_2 Y_3 Y_4 | \dots Y_9$$

SINGLE POINT

$$P_U = X_1 X_2 X_3 X_4 \mid X_5 X_7 X_8 X_9$$

$$P_U = Y_1 Y_2 Y_3 Y_4 \mid \dots Y_9$$

SINGLE POINT

Rare
Random

③ MUTATION

IZATION

GENETIC ALGORITHMS (GAs)

John Holland

David Goldberg → book

Work relations of candidates
 $P(1) \dots$

① encode solution as a string

Chromosome

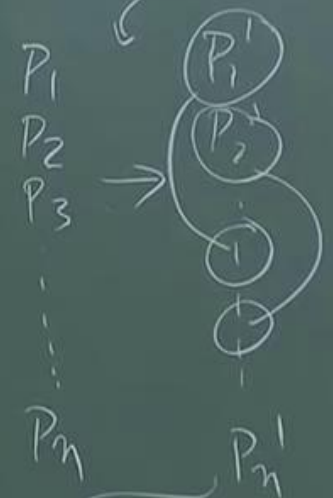
$eval(n)$
 $h(n)$

P_1''
 P_2''
 \vdots
 P_n''

$C_1 = X_1 X_2 X_3 X_4 Y_5 Y_6 \dots Y_9$
 $C_2 = Y_1 \dots Y_4 X_5 \dots X_9$

GA

① SELECTION



② CROSSOVER

$P_c = X_1 X_2$
 $P_u = Y_1 Y_2$

511

MINIMIZATION

GENETIC ALGORITHMS (GAs)

populations of candidates

John Holland

David Goldberg → book

① encode solution as a string

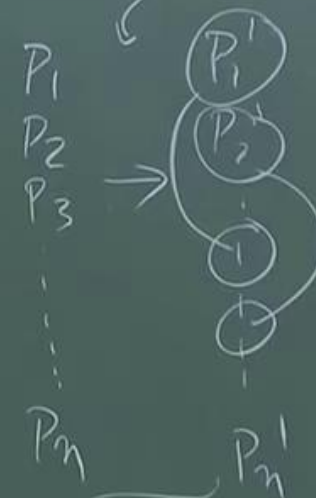
Chromosome

② Fitness function $f(n)$
 $\text{eval}(n)$
 $h(n)$

f
 P_1'
 P_2''
 \vdots
 P_n''

$C_1 = X_1 X_2 X_3 X_4 Y_5 Y_6 \dots Y_9$
 $C_2 = Y_1 \dots Y_4 X_5 \dots X_9$

GA
 ① SELECTION



② CROSSOVER

$P_i = X_1 X_2 \dots X_n$
 $P_j = Y_1 Y_2 \dots Y_n$

candidates

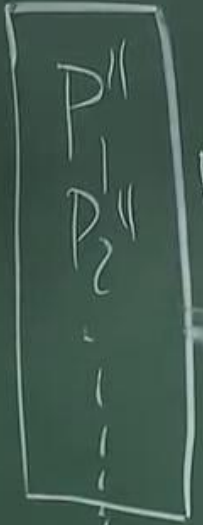
David Goldberg → Book

① encode solution as a string

Chromosome



$eval(x)$
 $h(x)$



$C_1 = X_1 X_2 X_3 X_4 Y_5 Y_6 \dots Y_9$
 $C_2 = Y_1 \dots Y_4 X_5 \dots X_9$

②

GENETIC ALGORITHMS (GAs)

John Holland

David Goldberg → book

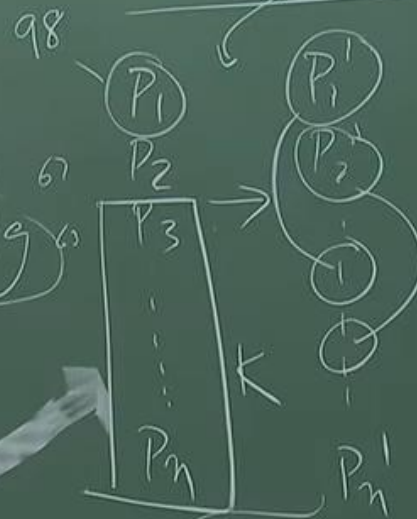
① encode solution as a string

fitness function $f(n)$
 $eval(n)$
 $h(n)$

Chromosome

GA

① SELECTION \propto fitness



Rare Random

③ MUTATION

② CROSSOVER

$$C_1 = X_1 X_2 X_3 X_4 X_5 X_6 \dots X_9$$

$$C_2 = Y_1 \dots Y_4 X_5 \dots X_9$$

$$P_1 = X_1 X_2 X_3 X_4 X_5 X_6 X_7 X_8 X_9$$

$$P_2 = Y_1 Y_2 Y_3 Y_4 \dots Y_9$$

SINGLE POINT



OPTIMIZATION

GENETIC ALGORITHMS (GAs)

John Holland

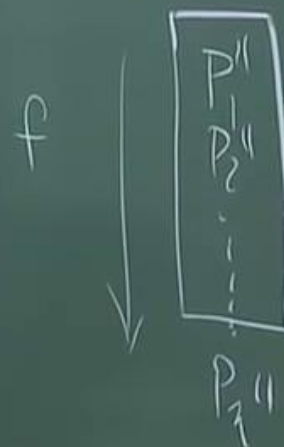
David Goldberg → book

work with populations of
 $P(n)$ candidates

① encode solution as a string

② Fitness function $f(n)$
 $eval(n)$
 $h(n)$

Chromosome



$$C_1 = X_1 X_2 X_3 X_4 X_5 X_6 \dots X_9$$

$$C_2 = X_1 \dots X_4 X_5 \dots X_9$$

GENETIC ALGORITHMS (GAs)

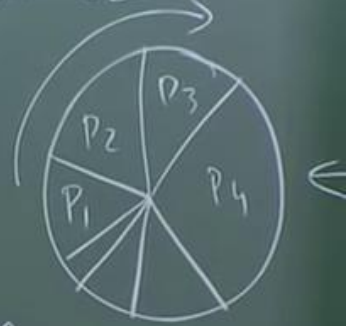
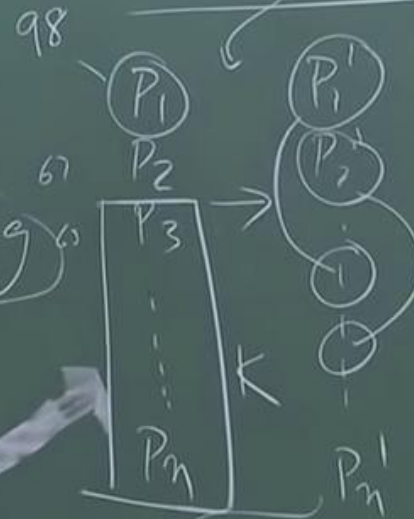
John Holland
David Goldberg → book
code solution as a string

populations
Candidates
Fitness $f(n)$

Chromosome

GA

① SELECTION \propto fitness



Rare Random
③ MUTATION

② CROSSOVER

$$C_1 = X_1 X_2 X_3 X_4 Y_5 Y_6 Y_7 Y_8 Y_9$$

$$C_2 = Y_1 \dots Y_4 X_5 \dots X_9$$

$$P_1 = X_1 X_2 X_3 Y_4 Y_5 X_6 X_7 X_8 X_9$$

$$P_2 = Y_1 Y_2 Y_3 Y_4 \dots Y_9$$

SINGLE POINT

$$P_1 = (2 \ 3 \ 7 \ 1 \ 4 \ 9 \ 6 \ 8 \ 5)$$

$$P_2 = (1 \ 2 \ 3 \ 4 \ 5 \ 6 \ 7 \ 8 \ 9)$$

Steve Grand - CREATION

↓ CREATURES

whatever persists, P

forms
compete for limited resources

PHENOTYPE
"then chooses"

fox
+
rabbit



OPTIMIZATION

GENETIC ALGORITHMS

Work with populations of candidates
 $P(1) \dots P(n)$
① encode

② Fitness function $f(n)$

$P_1 = (2 \ 3 \ 7 \ 1 \ 4 \ 9 \ 6 \ 8 \ 5)$

$P_2 = (2 \ 3 \ 4 \ 5 \ 6 \ 7 \ 8 \ 9)$ f

BEHAVIOUR

P_1''
 P_2''
 \vdots
 P_n''

John
David

eval(n)
 $h(n)$

Steve Grand - CREATION

↓ CREATURES

whatever persists, P

compete for limited

between

PHENOTYPE

"then chooses"

TYPE

being

fox

rabbit



NPTEL

OPTIMIZATION

GENETIC ALGORITHMS

Work with populations of
 $P(1) \dots P(n)$ Candidates

John

Davis

① encode

② Fitness function $f(n)$

eval

$h(n)$

$P_1 = (2 \ 3 \ 7 \ 1 \ 4 \ 9 \ 6 \ 8 \ 5)$

$P_2 = (1 \ 2 \ 3 \ 4 \ 5 \ 6 \ 7 \ 8 \ 9)$ f

P_1''
 P_2''
 \vdots
 P_n''

BEHAVIOUR

Steve Grand - CREATION

↓ CREATURES

Whatever persists.

forms
compete for resources

PHENOTYPE

"then chooses"

TYPE

fixing

for



NPTEL

OPTIMIZATION

→ GENETIC ALGORITHMS

Work with populations of
 $P(1) \dots P(n)$ Candidates

John

Darwin

① encode

② Fitness function $f(n)$

eval

$h(n)$

$$P_1 = (\underline{2} \ \underline{3} \ \underline{7} \ \underline{1} \mid 4 \ 9 \ 6 \ 8 \ 5)$$

$$P_2 = (\underline{1} \ \underline{2} \ \underline{3} \ \underline{4} \mid \underline{5} \ \underline{6} \ \underline{7} \ 8 \ 9) \ f$$

P_1''
 P_2''
 \vdots
 P_n''

P_3''

BEHAVIOUR