

The DU Map: A Visualization to Gain Insights into Genotype-Phenotype Mapping and Diversity

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<http://machinelearning.inginf.units.it>

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Grammar-based GP

- grammar-based GP approaches are popular
 - user just needs to provide the grammar and the fitness function
 - ensure valid individuals

Grammar-based GP

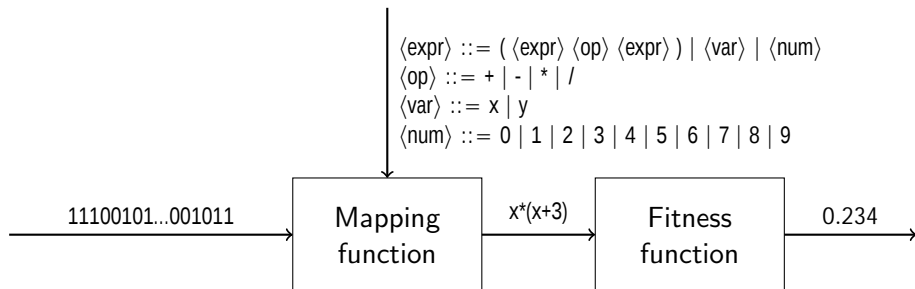
- grammar-based GP approaches are popular
 - user just needs to provide the grammar and the fitness function
 - ensure valid individuals
- among them, Grammatical Evolution (GE) widely used

The screenshot shows a Semantic Scholar search interface. At the top, the Semantic Scholar logo is on the left, and a search bar contains the text 'grammatical evolution'. Below the search bar, the results are filtered to show 'About 3,220 results'. On the left side, there is a 'Filter Results:' section with several filters: 'Full text PDF available (2,807)' (checked), 'Publication Year' (with a bar chart showing an increasing trend from 1964 to 2017, and sub-filters for 'This year (68)' and 'Last five years (987)'), 'Publication Type', 'Author', and 'Publication Venue'. The main content area displays the top results. The first result is 'Grammatical evolution' by Conor Ryan, published in GECCO in 2001. The abstract states: 'Grammatical Evolution is an automatic programming system that is a form of Genetic Programming structures. These structures can be in any form that can be specified using a grammar, in computer networks. When evolving computer languages, multiple types can be handled in a complete manner.' Below the abstract are links for 'View PDF', 'Related Publications', and 'More...'. The second result is 'Grammatical Evolution Evolutionary Automatic Programming Edition' by Maria Adler, published in 2016. The abstract for this result is partially visible: 'Number of pages: 197 pages Thank you for reading grammatical evolution evolutionary automatic programming in an arbitrary language 1st edition. Maybe you have knowledge that, people have look numerous times l evolution evolutionary automatic programming in an arbitrary language 1st edition, but en'.

GE

Three representations for the individual:

- genotype: a bit string
- phenotype: a string of the language defined by the CFG
- fitness



Genotype-phenotype mapping

Salient trait:

- allows using (standard) bit string genetic operators
- quite indirect mapping, poor variational inheritance
 - many variants proposed (GE, SGE, WHGE, ...)
 - large/hot debate: “GE mapping is bad!”¹, “No! It’s good!”²³

¹Whigham, Dick, and Maclaurin, “On the mapping of genotype to phenotype in evolutionary algorithms” .

²Squillero and Tonda, “(Over-)Realism in evolutionary computation: Commentary on “On the mapping of genotype to phenotype in evolutionary algorithms” by Peter A. Whigham, Grant Dick, and James Maclaurin” .

³Ryan, “A rebuttal to Whigham, Dick, and Maclaurin by one of the inventors of grammatical evolution: Commentary on “On the mapping of genotype to phenotype in evolutionary algorithms” by Peter A. Whigham, Grant Dick, and James Maclaurin” .

Mapping and properties

Mapping:

- invalidity: how often the mapping “fails”?
- redundancy⁴: is part of the genotype not used?
- degeneracy⁴: how often different genotypes are mapped to the same phenotype?

⁴Often, redundancy is used for degeneracy

Mapping and properties

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Mapping + genetic operators:

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Mapping + genetic operators:

- locality: are genotypic neighbors also phenotypic neighbors?
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Mapping + genetic operators + fitness:

- evolvability: is the child fitter than its parents?

⁴Often, redundancy is used for degeneracy

Properties: the big picture?

Several studies, some (conflicting) claims:

- degeneracy improves diversity⁵
- degeneracy causes lack of phenotypic diversity⁶
- neutrality (negatively) correlated with evolvability⁷
- degeneracy biased towards short individuals⁸
- diversity promotion leads to larger, better individuals⁹

⁵ O'Neill and Ryan, "Genetic code degeneracy: Implications for grammatical evolution and beyond".

⁶ Medvet, "A Comparative Analysis of Dynamic Locality and Redundancy in Grammatical Evolution".

⁷ Medvet, Daolio, and Tagliapietra, "Evolvability in grammatical evolution".

⁸ Thorhauer, "On the non-uniform redundancy in grammatical evolution".

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And some reasonable intuitions:

- evolvability is good
- redundancy) degeneracy) neutrality

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Studying GE and its properties

Often observed through coarse-grained measures:

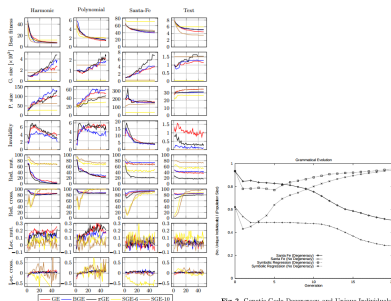


Fig. 2. Genetic Code Degeneracy and Unique Individuals

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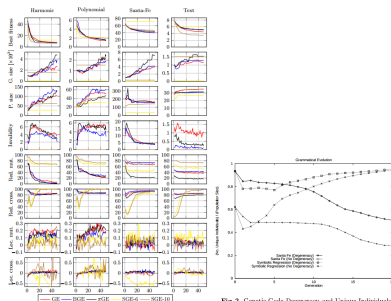


Fig. 2. Genetic Code Degeneracy and Unique Individuals

Can we look closer (and see better)?

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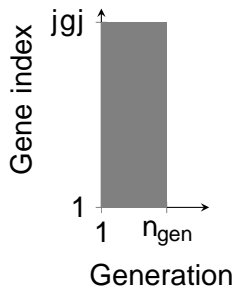
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Our proposal in a nutshell

A novel, compact visualization:

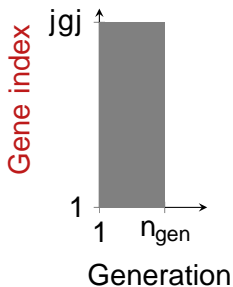
- genotypic **diversity** at the level of the single bit
- contribution (*usage*) of the single bit to the mapping
(: redundancy,) **degeneracy**)
- how they vary (**interact**) during the evolution

DU map: how to read it



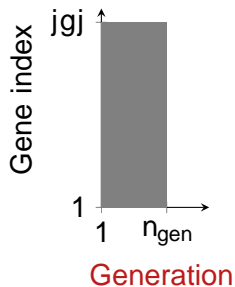
position:

DU map: how to read it



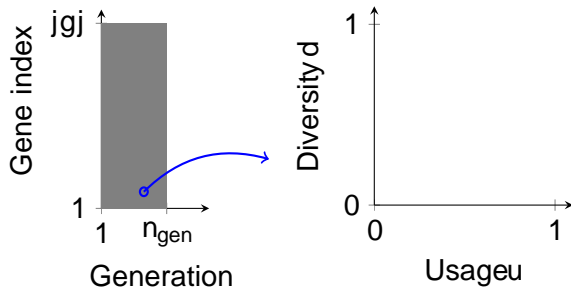
position: wherein the genotype?

DU map: how to read it



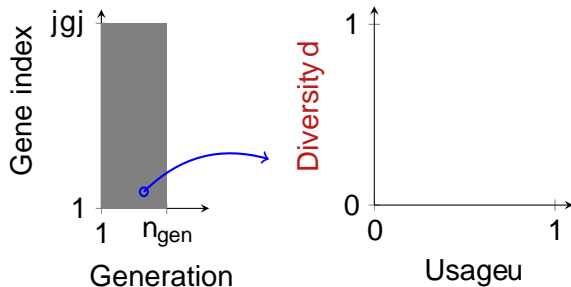
position: wherein the genotype? when during the evolution?

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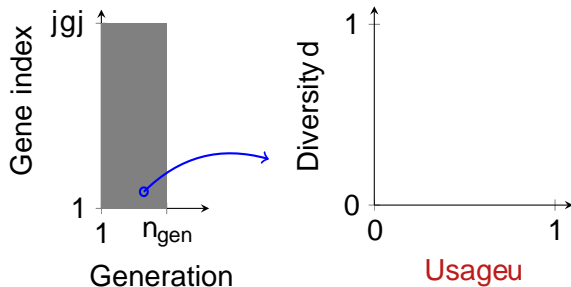
position: wherein the genotype?when during the evolution?
 color: for a given bit, at a given generation,

DU map: how to read it



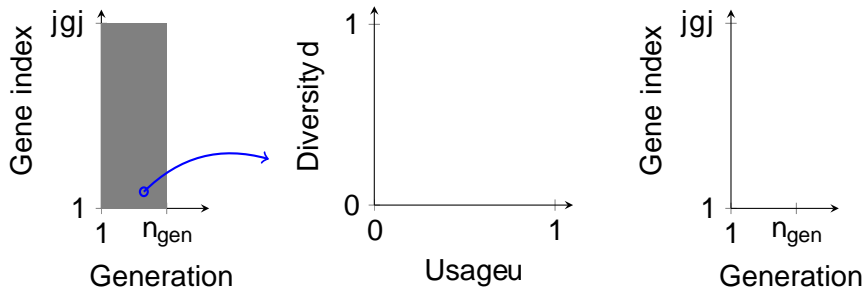
position: wherein the genotype? when during the evolution?
 color: for a given bit, at a given generation, how diverse is that bit now?

DU map: how to read it



position: wherein the genotype? when during the evolution?
 color: for a given bit, at a given generation, how diverse is that bit now? **to which degree is it used** now?

DU map: how to read it



position: wherein the genotype?when during the evolution?

color: for a given bit, at a given generation, how diverse is that bit now? to which degree is it used now?

all together: view of one run

How diverse is that bit? red channel i_{red}

$$i_{red}(x; y) = d(f g_y; s \in S_x g) \quad (1)$$

$d(A) \in [0; 1]$: a measure of diversity of a set of symbols

g_y : y th symbol of the genotype of the individuals

S_x : population at the x th generation

How diverse is that bit? red channel_{red}

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For bit string genotypes:

$$d(A) = 1 - \frac{1}{2} \frac{|\{a \in A : a = 0\}|}{|A|} \quad (2)$$

$d(A) = 0$ if all the same, $d(A) = 1$ if half 0 and half 1

Degree of usage of that bit! green channel i_{green}

$$i_{\text{green}}(x; y) = \frac{1}{|S_x|} \sum_{s \in S_x} u_y(g) \quad (3)$$

$u(g) \in [0; 1]^{|S_x|}$: a (vector) measure of usage of each symbol in S_x
 $u_y(g)$: y th component of the vector $u(g)$

Degree of usage of that bit! green channel i_{green}

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$u(g) \in [0; 1]^{|S_x|}$: a (vector) measure of usage of each symbol in

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For bit string genotypes:

$$u((g_1; g_2; \dots)) = \frac{1}{\max_{i \in \{1, 2, \dots, g\}} c_i} (c_1; c_2; \dots) \quad (4)$$

c_i : number of times i th bit been used during the mapping
depends on the mapping

$c_i \in \{0; 1; \dots; n_{\text{wrapping}}\}$ for GE, GE

$c_i \in \{0; 1\}$ for SGE

$c_i = 1$ for HGE/WHGE

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How to validate?

is the DU map better than its components?

is it helpful to understand GE and its properties?

can it be used to compare design options?

DU Map vs. its components

Poly4 benchmark, GE mapping w/ $w_{\text{wrapping}} = 10$, $|j| = 256$ bit, 100 generations

Best bits Diversity Usage DU map

DU Map vs. its components

Poly4 benchmark, GE mapping $w_{\text{wrapping}} = 10$, $j_{\text{g}} = 256$ bit, 100 generations

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initially, best evolves "everywhere", then only on a portion

DU Map vs. its components

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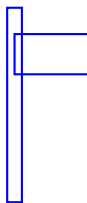


initially, best evolves "everywhere", then only on a portion

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Best bits Diversity Usage DU map



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- initially, diversity “everywhere”, then only on a portion

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- initially, used portion (and pheno size) increases

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Best bits Diversity Usage DU map



- initially, best evolves “everywhere”, then only on a portion
- initially, diversity “everywhere”, then only on a portion
- initially, used portion (and pheno size) increases
- **diversity is in unused (redundant) portion**) degeneracy) neutrality
) low phenotypic diversity

Comparing mappings and problems

GE GE BitSGE WHGE

Text

- “structure” of the genotype
- wrapping (GE, GE), no redundancy (WHGE)

Santa-Fe

Comparing mappings and problems

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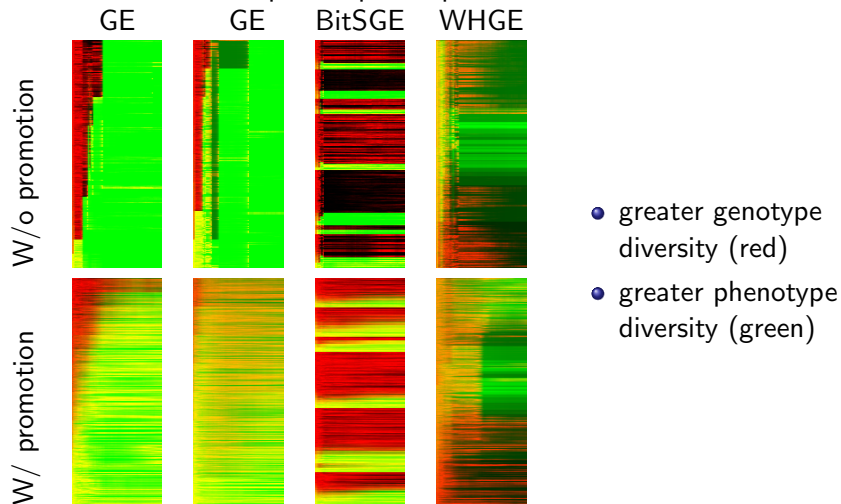
Text

Santa-Fe

- “structure” of the genotype
- wrapping (GE, GE), no redundancy (WHGE)
- phenotype size (estimate)

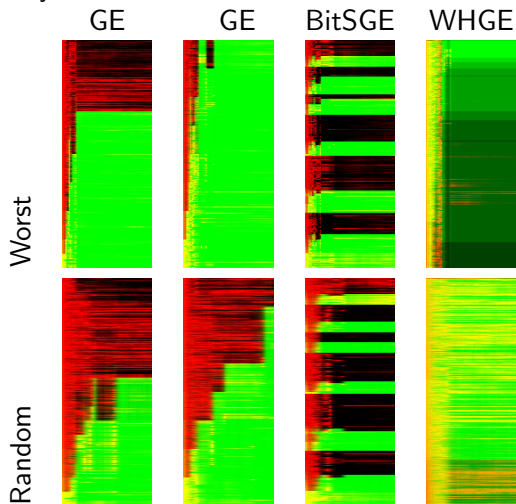
“Looking inside” diversity promotion

Harmonic, vanilla vs. phenotype uniqueness enforcement



“Looking inside” selection pressure

Poly4, remove worst vs. random



- more diversity (both genotype and phenotype)
- slower evolution

Conclusions

GE (and variants):

- used, studied, improved
- mapping properties effectiveness: still unclear

DU map:

- visualizes mapping, redundancy, diversity
- helps in designing improvements

Thanks!