Genetic Phase Angle Distance

computing pairwise codon distance using a 3-dimensional model of the genetic code.

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nonsequential, simultaneous interaction of **ALL** components

“imaginary space” (Anastassiou, 2001)
Nucleotides are mapped into a complex vector space, according to three biochemical properties.

- **e1 axis**: 2/3-hydrogen bonds
- **e2 axis**: Amino/Keto
- **e3 axis**: Purine/Pyrimidine

From Cristea, 2005

\[ \vec{a} = \vec{i} + \vec{j} + \vec{k}, \]
\[ \vec{c} = -\vec{i} + \vec{j} - \vec{k}, \]
\[ \vec{g} = -\vec{i} - \vec{j} + \vec{k}, \]
\[ \vec{t} = \vec{i} - \vec{j} - \vec{k}. \]

As represented in Mathematica using ‘clifford.m’ (Aragon, 2008; Zhang, 2006); Constructed by Pratt, 2013.
64 codons map to 64 unique vector positions, resulting in a tetrahedral genetic code. **GENETIC CODE MAPPING:** \( \delta_n(\text{codon}) = 4\alpha + 2\beta + \gamma; \) where \( \alpha = \) first, \( \beta = \) second, \( \gamma = \) third

\[
\delta_1(\text{GGG}) = 4(\hat{G}) + 2(\hat{G}) + \hat{G} = 4(-e_1 - e_2 + e_3) + 2(-e_1 - e_2 + e_3) + (-e_1 - e_2 + e_3) = -7e_1 - 7e_2 + 7e_3
\]

\[
\delta_2(\text{TTT}) = 4(\hat{T}) + 2(\hat{T}) + \hat{T} = 4(e_1 - e_2 - e_3) + 2(e_1 - e_2 - e_3) + (e_1 - e_2 - e_3) = 7e_1 - 7e_2 - 7e_3
\]
A matrix of all possible values of $\theta$ (small $\theta \rightarrow$ light, large $\theta \rightarrow$ dark).

(Pratt, 2013)

Phase distance $\theta$ is measured as the angle between sequentially neighboring codon vectors.
The coding sequences of the first exon of β-globin gene of eleven different species.

<table>
<thead>
<tr>
<th>Species</th>
<th>Coding sequence</th>
<th>((N=30))</th>
</tr>
</thead>
<tbody>
<tr>
<td>1. Human</td>
<td></td>
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<tr>
<td>2. Chimpanzee</td>
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<tr>
<td>3. Goat</td>
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<td>4. Bovine</td>
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<td>5. Gallus</td>
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<td>6. Mouse</td>
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<td>7. Rat</td>
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<td>8. Gorilla</td>
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<td>9. Rabbit</td>
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<td>10. Opossum</td>
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<tr>
<td>11. Lemur</td>
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</tr>
</tbody>
</table>

Alignment made in MEGA5 software using MUSCLE (codon) algorithm (N=30)

Phase angle \(\theta\) sequence maps for species: Human (blue), Chimpanzee (red), and Gallus (gold)
Angular difference $\Delta \theta$ is computed as the absolute value of the difference in phase $\theta$ between species under investigation, at equivalent (aligned) genetic loci.

shaded: $\Delta \theta_{HG} = | \Delta \theta(\text{Human}) - \Delta \theta(\text{Gallus}) |$

Genetic Phase Angle Distance

$$\frac{2}{\pi \times N} \sum \{ \Delta \theta_n, \ldots, \Delta \theta_{N-1}, \Delta \theta_N \}$$

(Pratt, 2013)
For comparison, Tamura-3 distance measure computed using MEGAS5.
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