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Homeobios: The Pattern of Heartbeats in Newborns, Adults, and Elderly Patients

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[COLOR FIGURES]

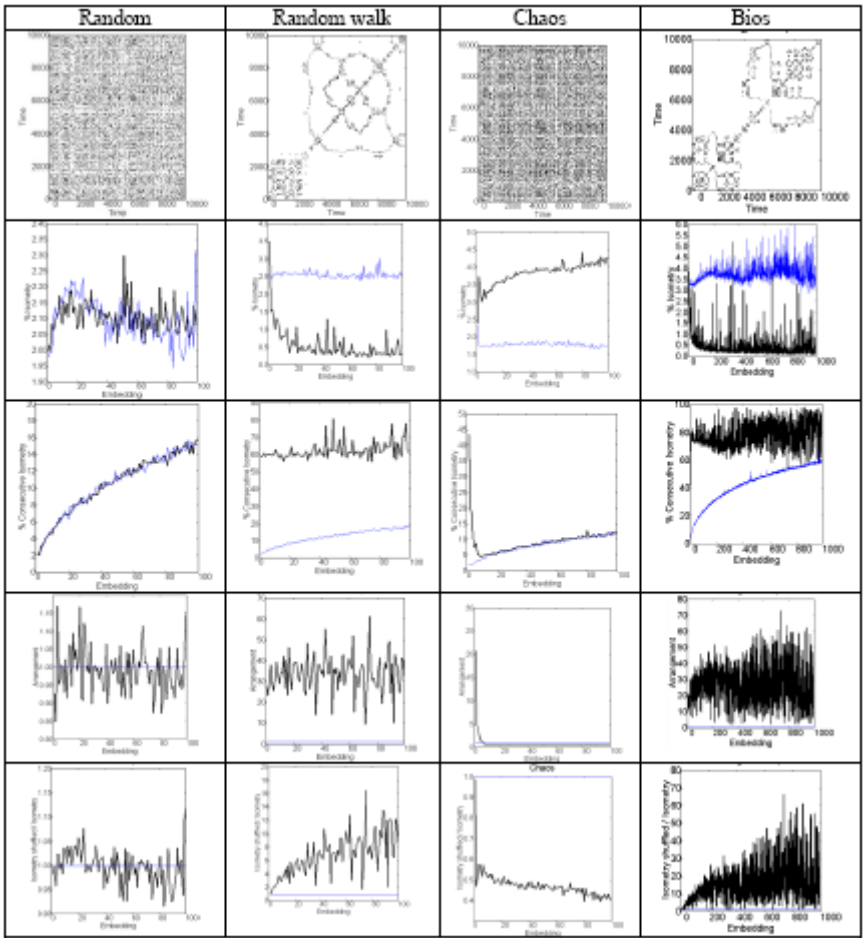


Fig. 1. Mathematical bios. *Top row:* The series of patterns generated by the process *(left)* and the diversifying equations *(right). Y* axis: $\log_2(A_t)$. *X* axis: gain *kt*. *Lower rows:* Creative features in bios (diversifying equation), as contrasted to other non-periodic mathematical series.

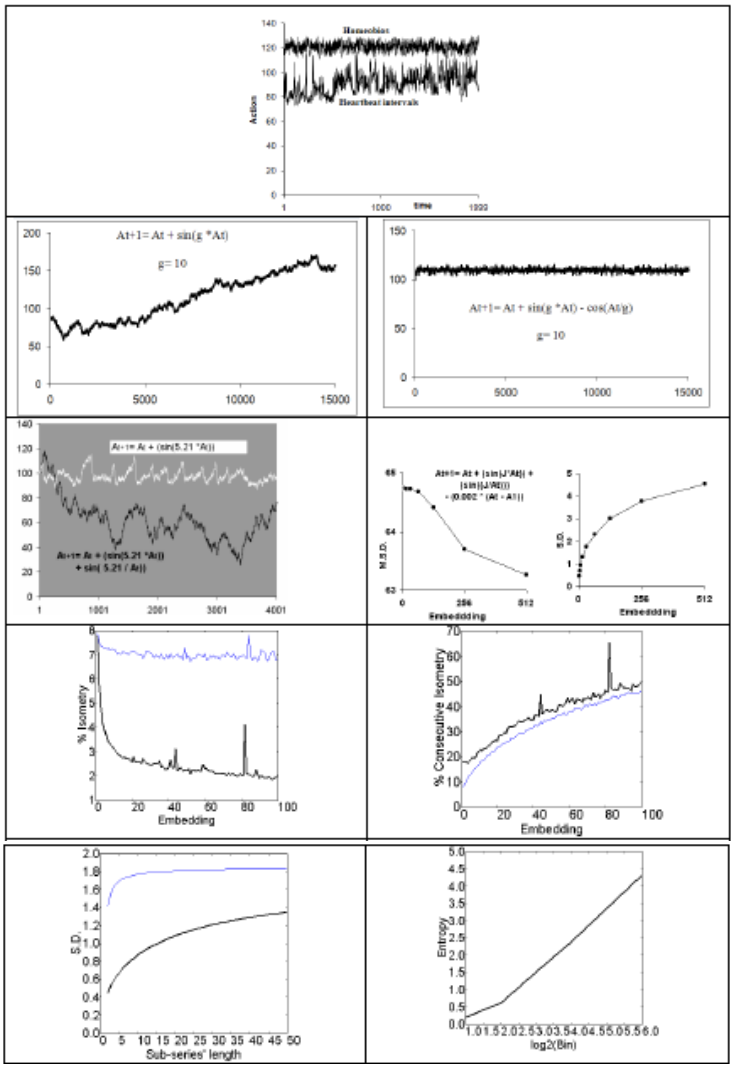


Fig. 2. Homeobios and RRI series. *Top row:* comparison of RRI series with a homeobiotic series generated by trigonometric recursion. *Second row:* comparison of a biotic and a homeobiotic series generated by trigonometric recursions. *Third row:* $C_{t+1} = C_t + \sin(gC_t) + \sin(g/C_t)$ and the generation of diversification without diffusion. *Fourth and fifth row:* creative features of homeobios generated by the diversifying equation (J= 18) with negative feedback (compared to randomized copy in blue): low isometry, high consecutive recurrence, increasing standard deviation and low entropy.

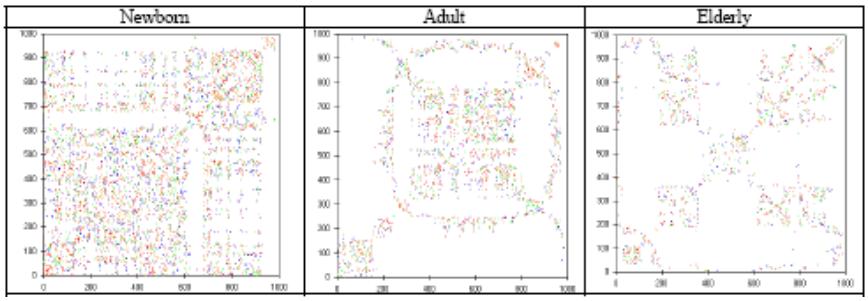


Fig. 3. RRI series in newborn, adult and elder healthy persons. Complements plots *(top row),* wavelet plots *(middle row),* and recurrence plots (10 embeddings and 10 percent cutoff radius, bottom row).

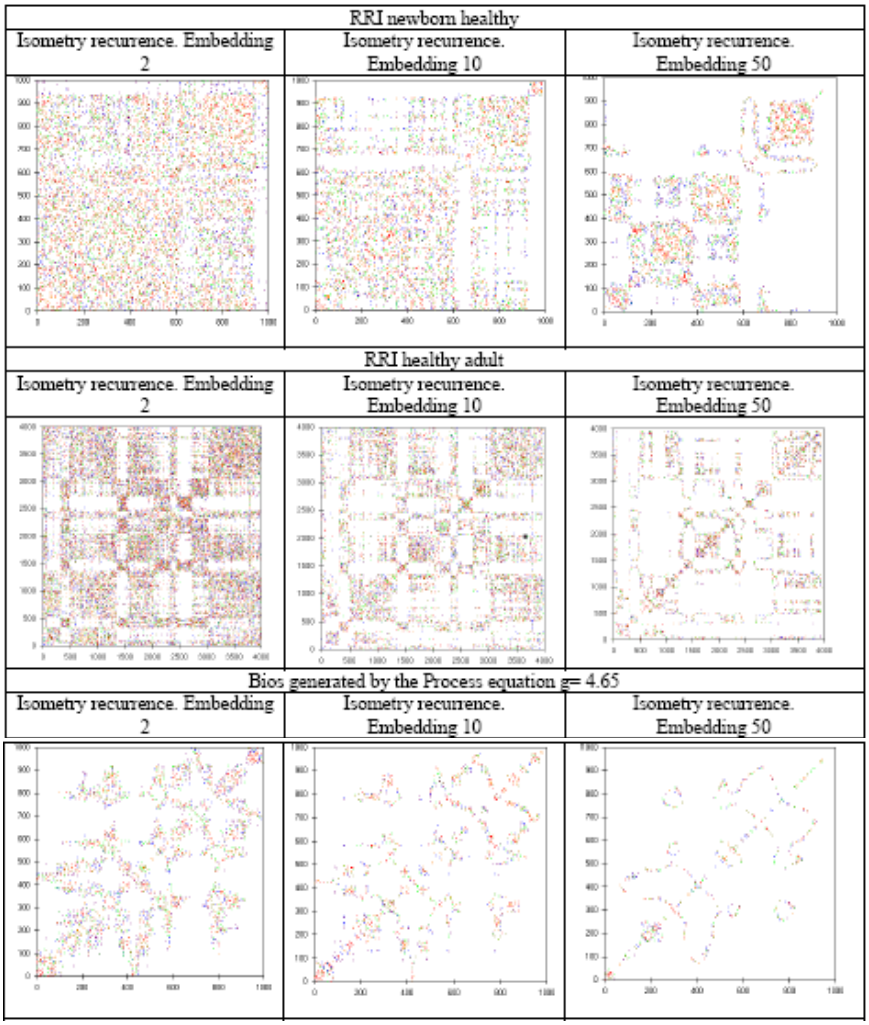


Fig. 4. Isometry at various embeddings for RRI series (healthy newborn baby and healthy adult) and in bios series generated mathematically. Cutoff = 10.

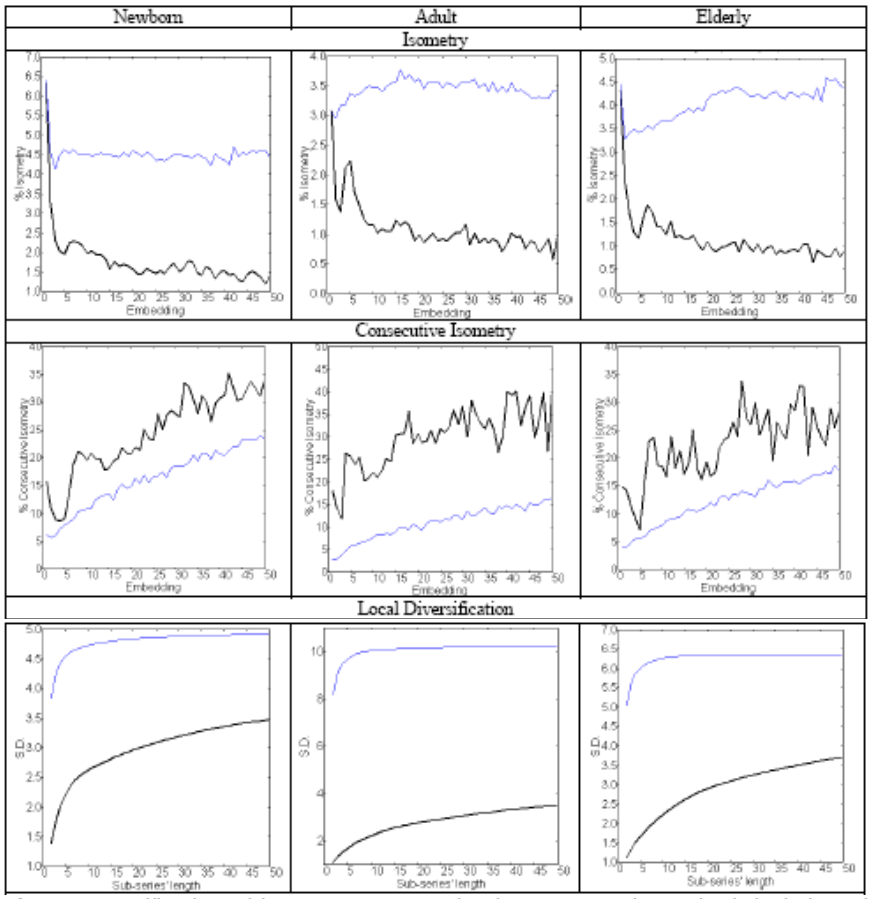


Fig. 5. Quantification of isometry, consecutive isometry, and standard deviation of vectors of successive RRIs as a function of vector length (embedding). *Black:* original series. *Blue:* shuffled copy.

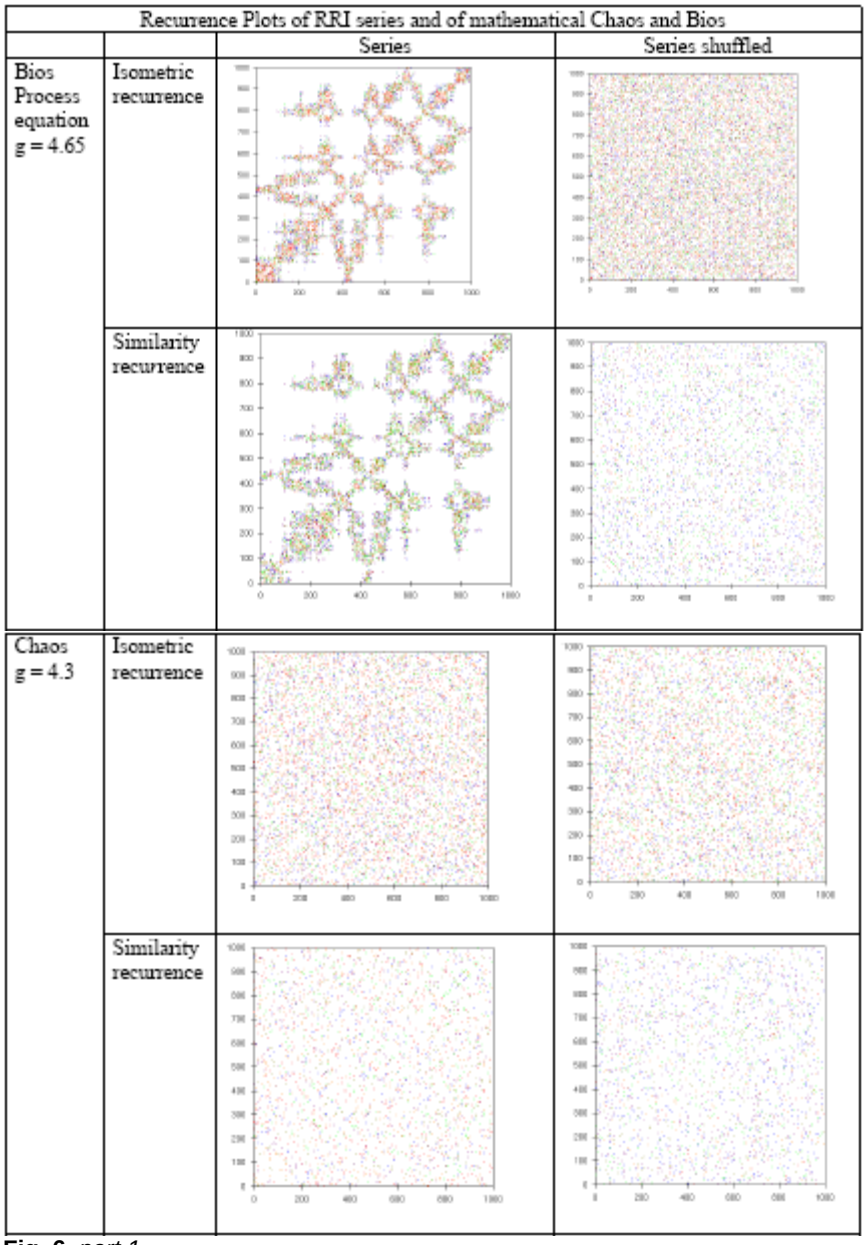

Recurrence Plots of RRI series and of mathematical Chaos and Bios
Series
Series shuffled
Bios Process equation g = 4.65
Isometric recurrence
Similarity recurrence
Chaos g = 4.3
Isometric recurrence
Similarity recurrence

Fig. 6. *part 1*.

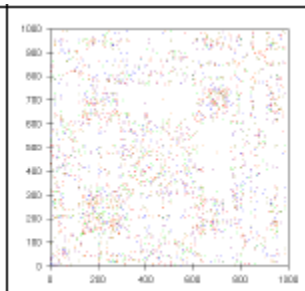
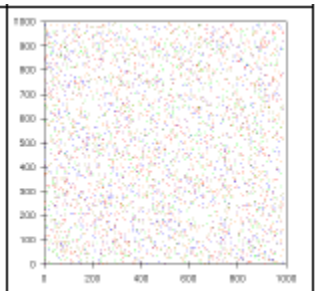
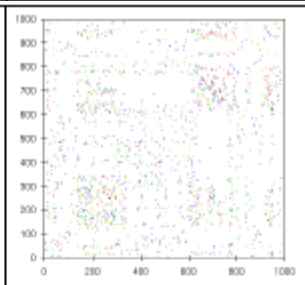
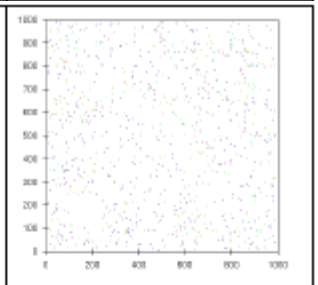
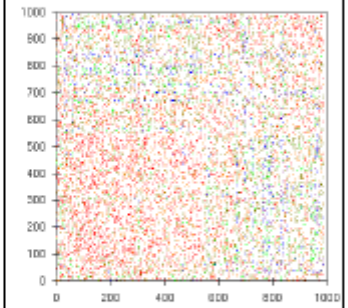
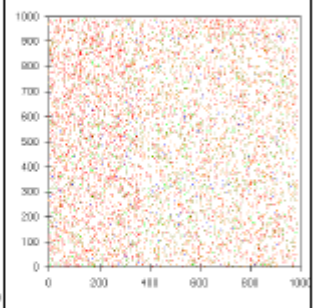
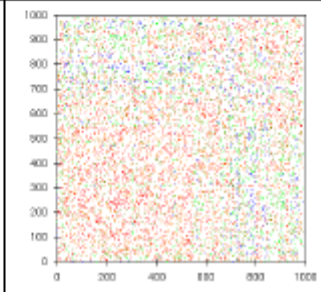
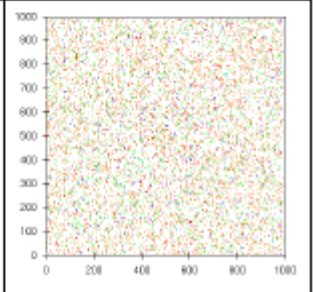
RRI normal newborn	Isometric recurrence		
	Similarity recurrence		
RRI newborn with severe con-genital cardiac illness	Isometric recurrence		
	Similarity recurrence		

Fig. 6. *part 2*.

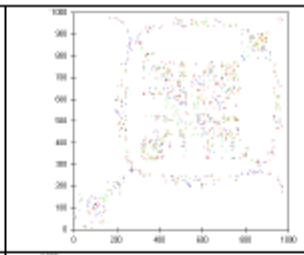
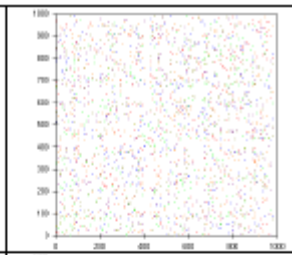
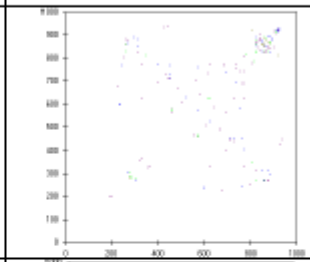
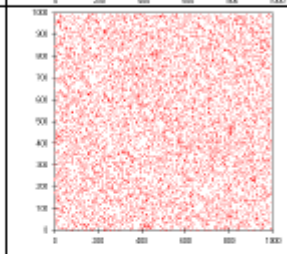
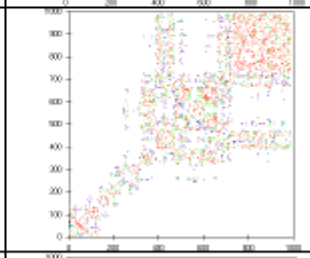
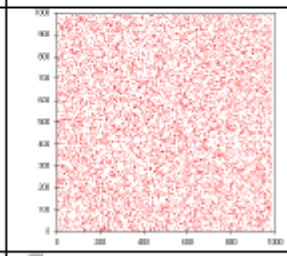
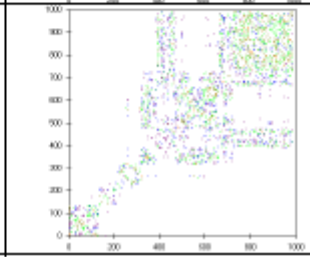
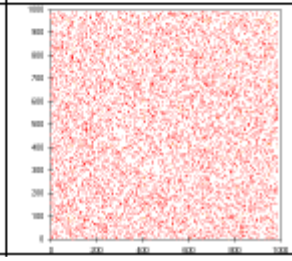
Healthy adult	Isometric recurrence		
	Similarity recurrence		
Adult with cardiac failure	Isometric recurrence		
	Similarity recurrence		

Fig. 6. *part 3.*

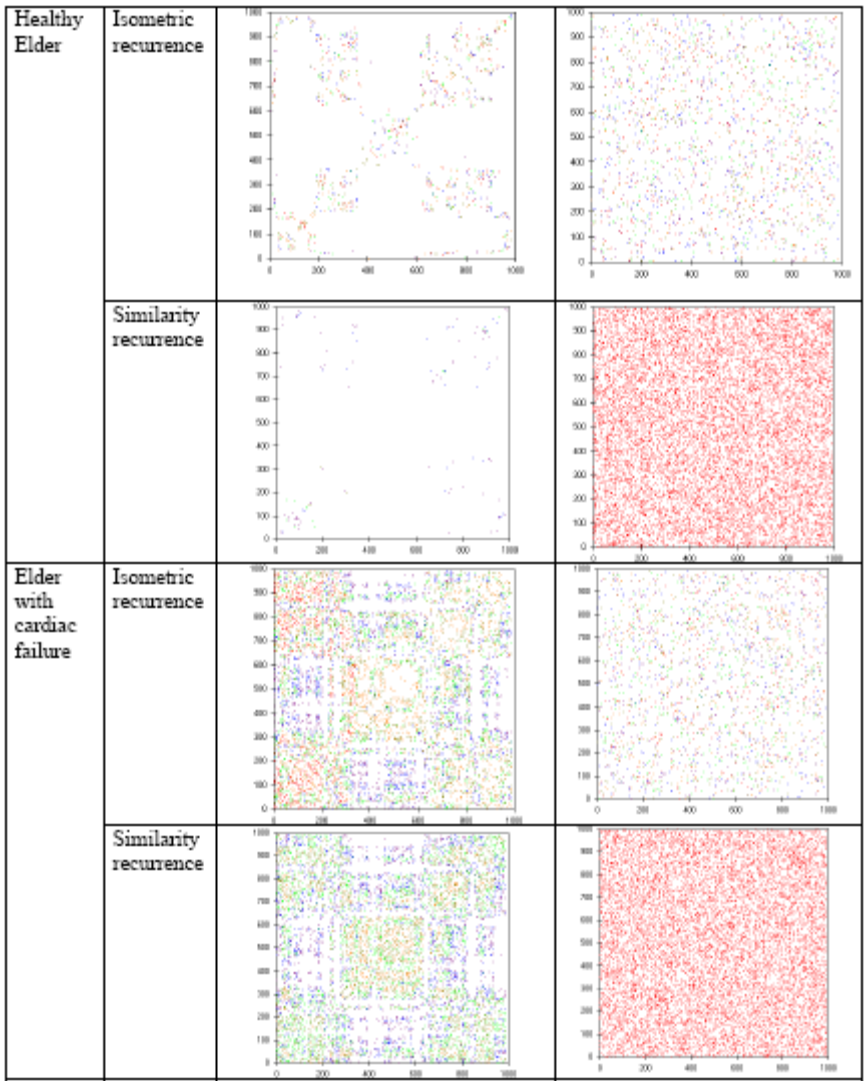


Fig. 6. Recurrence plots of series and their shuffled copies. Embedding 2. Cutoff radius: 2 for Chaos, 10 for all others series. 20,000 comparisons. *Left:* original series with distinct complexes. *Right:* Shuffled copy. When the data are randomized, complexes disappear, and the number of recurrences increases, indicating that the physiological process heartbeats generates more novelty than what can be expected by chance. This measure of novelty, absent in chaotic attractors, is found bios as well as in Brownian and pink noise.

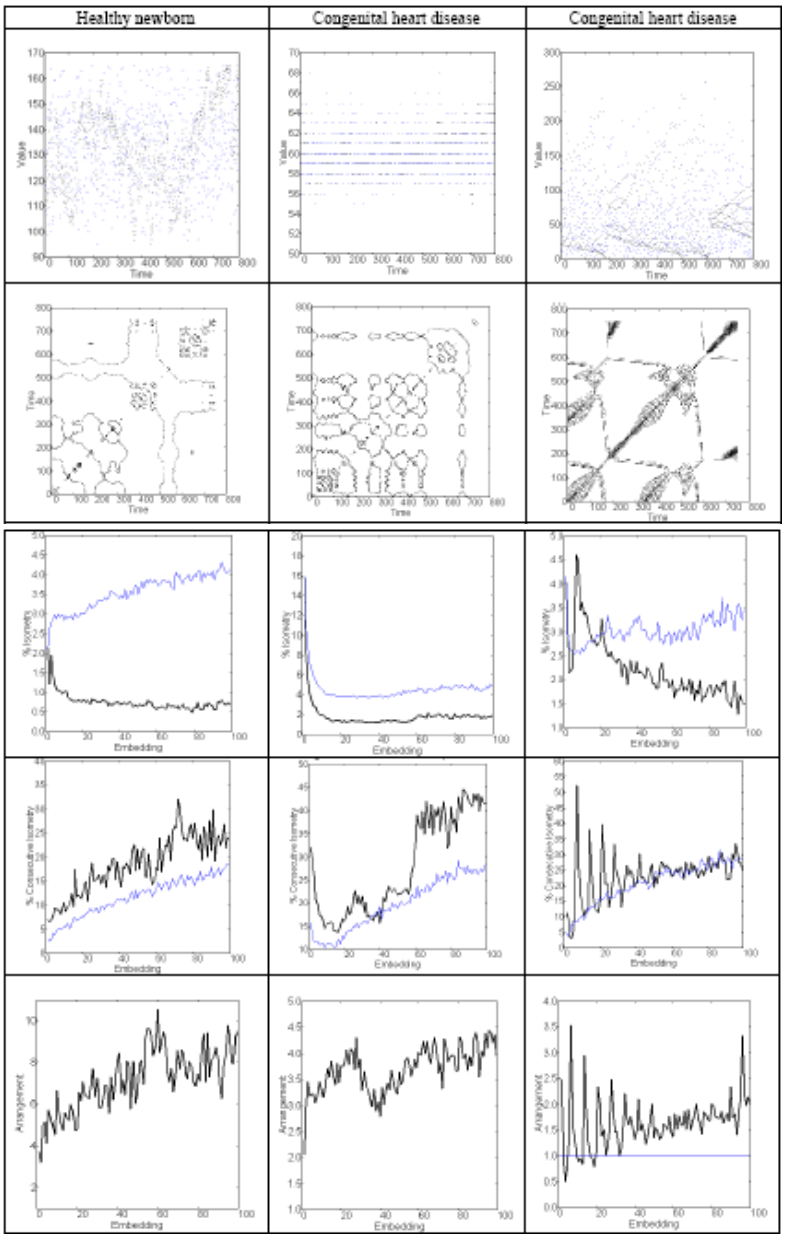

Healthy newborn
Congenital heart disease
Congenital heart disease
Value
Time
% Isonality
% Consecutive Isonality
Arrangement
Embedding

Fig. 7, *part 1.*

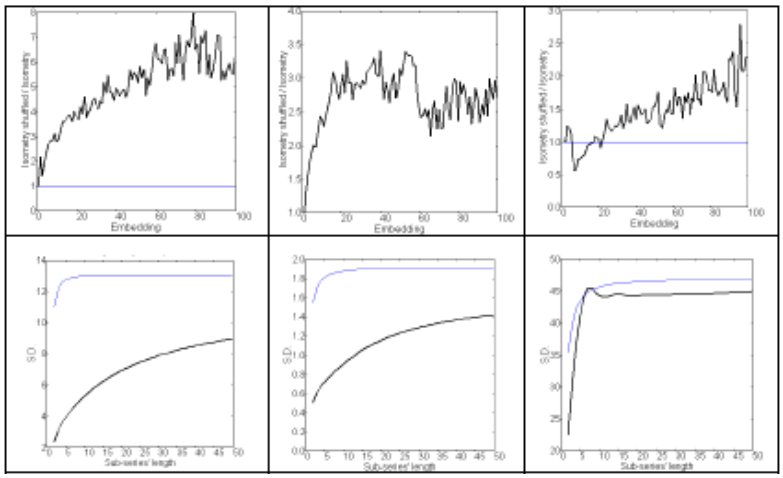


Fig. 7. Quantification of creative features in RRI series from healthy and cardiologically impaired newborns: *Top row:* time series (black dots) and shuffled copy (blue dots). *Second row:* recurrence plot at 50 embeddings. *Third row:* Percentage of isometry recurrences. *Fourth row:* Percentage of consecutive isometries. *Fifth row:* arrangement (consecutive isometry / isometry). *Sixth row*: novelty (increase in isometry by shuffling). *Seventh row:* local diversification (SD as a function of the number of embeddings). *Black:* original series. *Blue:* shuffled copy.

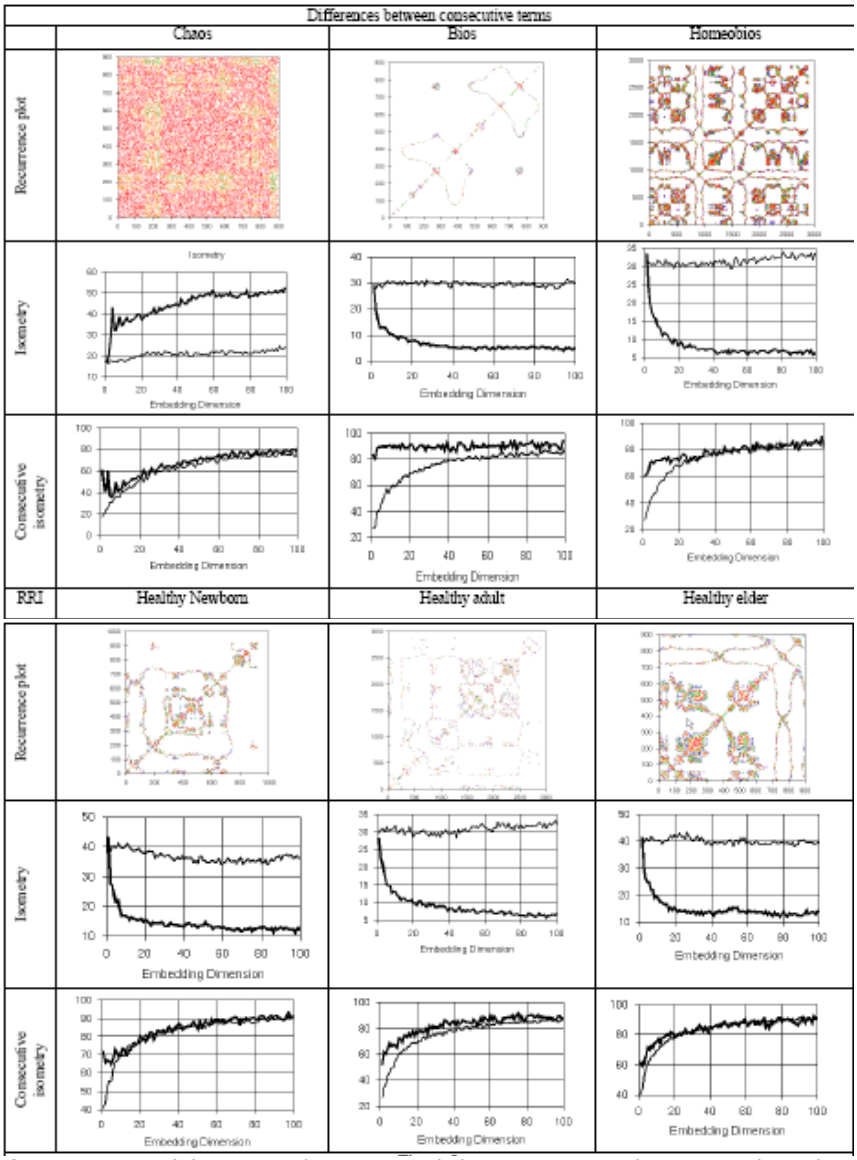


Fig. 8. Determinism, as demonstrated by recurrence isometry plots (100 embeddings, 5 cutoff radius, 15000 comparisons), number of isometries, and number of consecutive isometries in series of differences between consecutive terms in RRI series of healthy newborns, adults and elders, and in mathematically generated chaotic, biotic and homeobiotic series.

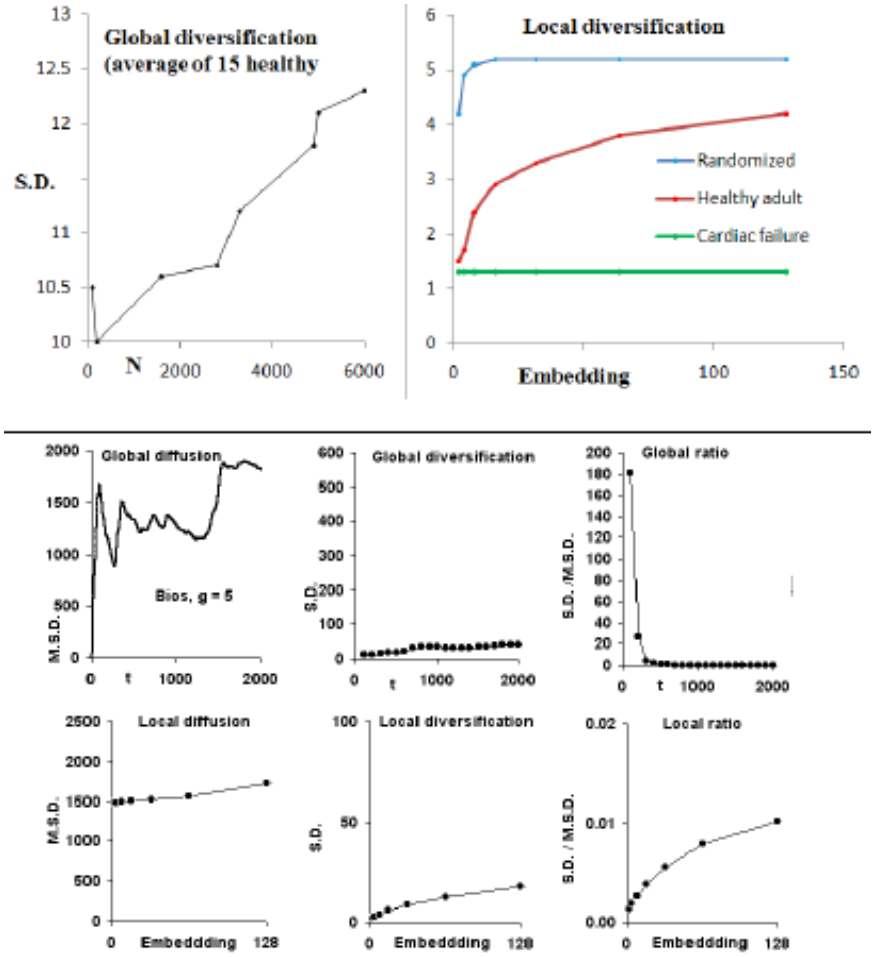


Fig. 9. Diversification and diffusion. *Top:* RRI series show both global and local diversification. *Bottom:* the SD / diffusion decreases with duration of the series and increases with embedding.