New Method for Comparing Somatotypes using Logical-Combinatorial Approach

Ignacio Acosta-Pineda[1] and Martha R. Ortiz-Posadas[2]

[1] Master in Biomedical Engineering
[2] Department of Electrical Engineering,
Universidad Autónoma Metropolitana Iztapalapa, Mexico
nss_33@hotmail.com, posa@xanum.uam.mx

Abstract. This paper proposes a new method for comparing somatotypes using the logical-combinatorial approach of pattern recognition theory, through the mathematical modeling of a function to evaluate the similarity between somatotypes, considering the 10 anthropometric dimensions defined in the Heath-Carter method. This similarity function was applied to a sample of different individual somatotypes and the results were compared with the ones obtained by the two methods most commonly used: the somatotype dispersion distance and the somatotype attitudinal distance. We obtained correct results with the method presented in this work and it offers a new perspective for comparison between somatotypes.

Keywords: Somatotype comparison, somatotype similarity, Heath-Carter method, logical-combinatorial approach, pattern recognition.

1 Introduction

The term somatotype corresponds in such a way with the biotype term, and is one of the most frequent tasks of Kineanthropometry, the discipline that studies the human body through the measures and assessments of their size, shape, proportionality, composition, biological maturation and body functions. The technique of somatotyping is used to appraise body shape and composition. Somatotype concept is very useful in different areas of healthcare, such as diet monitoring, effect of ergogenic aids, eating disorders and/or sport sciences, in order to compare an athlete somatotype with his/her team, or with a standard reference, or with a normal population, or itself at different stages of the training [1].

The somatotype is defined as the quantification of the present shape and composition of the human body. It is expressed in a three-number rating representing endomorphy, mesomorphy and ectomorphy components respectively, always in the same order. Endomorphy is the relative fatness, mesomorphy is the relative muscle-skeletal robustness, and ectomorphy is the relative linearity or slenderness of a physique. To calculate these components it is used the anthropometric somatotype method of Heath-Carter [1], where 10 anthropometric dimensions (variables) are needed. Three variables (in millimeters) are required for the measurement of endomorphy: triceps skinfold, subscapular skinfold and supraspinale skinfold; these are introduced in equation (1) in order to obtain the endomorphy component.

$$Endomorphy = -0.72 + 0.15x - 0.0007x^2 + 0.0000014x^3 \quad (1)$$

Where x = [(sum of the three folds)*170.8]/(height in cm).

For measuring mesomorphy, five measurements (in centimeters) are needed: U = humerus breadth, F = femur breadth, B = upper arm girth−triceps skinfold, P = calf girth−medial calf skinfold, H = height; and these are entered into equation (2).

$$Mesomorphy = 0.86U + 0.60F + 0.19B + 0.16P - 0.13H + 4.5 \quad (2)$$

Ectomorphy calculation needs height in centimeters and weight in kilograms, and the calculation of *HWR* (height-weight ratio) by equation (3).

$$HWR = \frac{height}{\sqrt[3]{weight}} \quad (3)$$

If HWR <= 38.28,	ectomorphy = 0.1
If 38.28<*HWR*<40.75,	ectomorphy = (*HWR**0.463) –17.63
If *HWR* >= 40.75,	ectomorphy = (*HWR**0.732)–28.58 [1]

Traditionally, the three-number somatotype rating is plotted on a two-dimensional somatochart (Fig. 1) using *X*, *Y* coordinates derived from the rating. The coordinates are calculated by equations (4) and (5) respectively.

$$X = ectomorphy - endomorphy \quad (4)$$

$$Y = 2(mesomorphy) - (ectomorphy + endomorphy) \quad (5)$$

Somatotypes with similar relationships between the dominance of the components are grouped into thirteen categories named to reflect these relationships. These categories are shown in the somartochart of Fig. 1.

Because the somatotype is a three-number expression, meaningful analyses can be conducted only with special techniques. Somatotype data has been analyzed by methods such as the somatotype dispersion distance (SDD), that is the difference between two individual somatotypes of interest [1] and it is defined by equation (6)

$$SDD = \sqrt{3(X_1 - X_2)^2 + (Y_1 - Y_2)^2} \quad (6)$$

Where X_1 and Y_1 are the somatotype coordinates of the individual 1, and X_2 and Y_2 are the coordinates of the individual 2 Where X_1 and Y_1 are the somatotype coordinates of the individual 1, and X_2 and Y_2 are the coordinates of the individual 2.

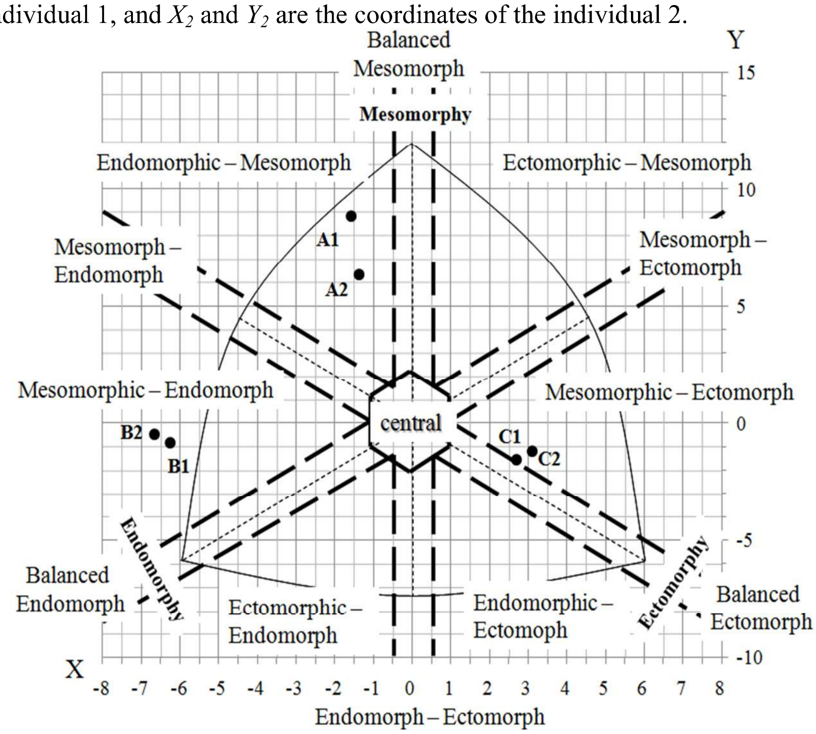

Fig. 1. Somatochart with the 13 somatotype categories [1] and location of the six somatotypes selected for this study.

Other method is the somatotype attitudinal distance (SAD) that is the difference in component units between two somatotypes and is defined by (7).

$$SAD = \sqrt{(I_A - I_B)^2 + (II_A - II_B)^2 + (III_A - III_B)^2} \tag{7}$$

where A and B are two individual somatotypes and I, II and III are the endomorphy, mesomorphy and ectomorphy component respectively of the individual somatotype [1].

For many works attempting mathematical modeling, the likelihood between two objects may be represented using a function of distance (a norm) since closeness and likelihood have generally been treated as synonyms: two objects are more alike the closer they are found from each other and, given this, it is possible to agree if some details are specified, such as the space of representation of the objects, the kind of variables (qualitative or quantitative) which describe them, their domains, the comparison criteria for their values, etc. Likewise, it is important to consider the way in which full object descriptions are attempted. In this sense, it is important to distinguish between likelihood and closeness in those cases where these terms are not synonyms.

This paper proposes a new method for comparing somatotypes, using the logical-combinatorial approach of pattern recognition theory [2], through the mathematical modeling of a function to evaluate the similarity between two somatotypes, considering the 10 anthropometric dimensions defined in the Heath-Carter method [1], and defining differential comparison criteria for each variable. The similarity function was applied to 6 different individual somatotypes, and these results were compared with the results obtained by both methods SDD and SAD.

2 Methodology

2.1 Mathematical Model [3]

Let $O = \{O_1, \ldots, O_m\}$ be a finite set of m objects, each object is described in terms of the finite set of variables $X= \{x_1, \ldots, x_n\}$, where each variable x_i, $i=1, \ldots, n$ is defined on its domain $M_i = \{m_{i1}, m_{i2}, \ldots\}$.

Definition 1. Let the initial space representation (ISR) be the object space representation defined by the Cartesian product of M_i sets

$$I(O) = (x_1(O), \ldots, x_n(O)) \in (M_1 \times \ldots \times M_n)$$

Where $I(O)$ is the object description of O in terms of the variables x_i, $i=1, \ldots, n$. $x_i(O)$ is the value taken by the variable x_i in the object O.

Definition 2. Let $\mathbf{C} = \{C_1, \ldots, C_n\}$ be a set of functions called comparison criteria for each variable $x_i \in X$ such as: $C_i: M_i \times M_i \rightarrow \Delta_i$; $i=1, \ldots, n$ where Δ_i can be of any nature, it is an ordered set and can be finite or infinite.

Definition 3. Let $\omega \subseteq X$ be a support set, where $\omega \neq \{\emptyset\}$. A system of support sets is defined as $\Omega = \{\omega_1, \ldots, \omega_s\}$. By ωO we denote the ω-part of O formed by the variables $x_j \in \omega m$, $m=1, \ldots, s$.

The system of support sets Ω will allow analysis of the objects to be classified, done by paying attention to different parts or sub-descriptions of the objects, and not analyzing the complete descriptions. Examples of systems of support sets are combinations with a fixed cardinality, combinations with variable cardinality, the power set of features, etc.

The analogy between two objects is formalized by the concept of similarity function. This function is based on the comparison criterion C_i generated for each variable x_i. It is important to mention that the similarity function can evaluate the similarity or difference between two objects, i.e., between their descriptions.

Definition 4. Let $\beta:(M_i \times M_i)^2 \rightarrow \Delta$ be the similarity function, where Δ (as in the comparison criterion function) can be of any nature; it is an ordered set and can be finite or infinite. For $I(O_i)$ and $I(O)$ being two object descriptions in the domain $(M_1 \times \ldots \times M_n)$, $\beta(I(O_i), I(O))$ is defined by:

- $\beta((C_1(x_1(O_i), x_1(O)), \ldots, C_n(x_n(O_i), x_n(O))))$, if C_i denotes similarity
- $1 - \beta((C_1(x_1(O_i), x_1(O)), \ldots, C_n(x_n(O_i), x_n(O))))$, if C_i denotes difference

Definition 5. Let β_ω be a partial similarity function defined by:

$$\beta_\omega\left(I(O_i), I(O_j)\right) = 1 - \sum_{x_i \in \omega} C_i\left(x_i(O_i), x_i(O)\right) \tag{8}$$

where ω represents a support set.

2.2 Somatotype Mathematical Model

We used the 10 anthropometric dimensions (variables) proposed in the Heath-Carter method [1], described in the introduction. It was defined their domain by previously classifying 38 subjects [4], and the difference comparison criteria (*Definition 2*), shown in Table 1. The 0 means there is no difference and 1 represents the greatest difference between the two values compared.

Table 1. Somatotype variables, domain and comparison criteria.

Variable	Domain	Comparison criteria
***x₁*:** Supraspinale skinfold	[6, 55]	$C_2(x_2(O_i), x_2(O_j)) = \begin{cases} 1 & if \ \frac{\lvert x_2(O_i) - x_2(O_j)\rvert}{49} \le 0.1 \\ 0 & in\ other\ case \end{cases}$
***x₂*:** Subscapular skinfold	[8, 41]	$C_2(x_2(O_i), x_2(O_j)) = \begin{cases} 1 & if \ \frac{\lvert x_2(O_i) - x_2(O_j)\rvert}{33} \le 0.1 \\ 0 & in\ other\ case \end{cases}$
***x₃*:** Triceps skinfold	[4, 25]	$C_2(x_2(O_i), x_2(O_j)) = \begin{cases} 1 & if \ \frac{\lvert x_2(O_i) - x_2(O_j)\rvert}{21} \le 0.1 \\ 0 & in\ other\ case \end{cases}$
***x₄*:** Medial calf skinfold	[0.5, 3.0]	$C_2(x_2(O_i), x_2(O_j)) = \begin{cases} 1 & if \ \frac{\lvert x_2(O_i) - x_2(O_j)\rvert}{2.5} \le 0.1 \\ 0 & in\ other\ case \end{cases}$
***x₅*:** Calf girth, right	[30.0, 43.0]	$C_2(x_2(O_i), x_2(O_j)) = \begin{cases} 1 & if \ \frac{\lvert x_2(O_i) - x_2(O_j)\rvert}{13} \le 0.5 \\ 0 & in\ other\ case \end{cases}$
***x₆*:** Upper arm girth, elbow flexed and tensed	[29.0, 41.0]	$C_2(x_2(O_i), x_2(O_j)) = \begin{cases} 1 & if \ \frac{\lvert x_2(O_i) - x_2(O_j)\rvert}{12} \le 0.5 \\ 0 & in\ other\ case \end{cases}$

x₇: Biepicondylar breadth of the femur	[8.0, 12.0]	$C_2\big(x_2(O_i),x_2(O_j)\big)=\begin{cases}1 & if\ \frac{\lvert x_2(O_i)-x_2(O_j)\rvert}{4}\leq 0.5\\ 0 & in\ other\ case\end{cases}$
x₈: Biepicondylar breadth of the humerus	[5.0, 8.0]	$C_2\big(x_2(O_i),x_2(O_j)\big)=\begin{cases}1 & if\ \frac{\lvert x_2(O_i)-x_2(O_j)\rvert}{3}\leq 0.5\\ 0 & in\ other\ case\end{cases}$
x₉: Body mass (weight)	[51.0, 120.0]	$C_2\big(x_2(O_i),x_2(O_j)\big)=\begin{cases}1 & if\ \frac{\lvert x_2(O_i)-x_2(O_j)\rvert}{69}\leq 0.1\\ 0 & in\ other\ case\end{cases}$
x₁₀: Stature (height).	[157.0, 190.0]	$C_2\big(x_2(O_i),x_2(O_j)\big)=\begin{cases}1 & if\ \frac{\lvert x_2(O_i)-x_2(O_j)\rvert}{33}\leq 0.1\\ 0 & in\ other\ case\end{cases}$

We defined three support sets (*Definition 3*), one for each somatotype component: $\Omega_{\text{endo}} = \{x_1, x_2, x_3, x_{10}\}$; $\Omega_{\text{meso}} = \{x_3, x_4, x_5, x_6, x_7, x_8\}$; $\Omega_{\text{ecto}} = \{x_9, x_{10}\}$. Likewise using *Definition 5*, we defined three partial similarity functions described below:

$$\beta_{\text{endo}}\left(\Omega I(O_i),\Omega I(O_j)\right) = 1-\sum_{t=1,2,3,10}\frac{C_t\big(x_t(O_i),x_t(O_j)\big)}{4} \quad (9)$$

$$\beta_{meso}\left(\Omega I(O_i),\Omega I(O_j)\right) = 1-\sum_{t=3}^{8}\frac{C_t\big(x_t(O_i),x_t(O_j)\big)}{6} \quad (10)$$

$$\beta_{ecto}\left(\Omega I(O_i),\Omega I(O_j)\right) = 1-\sum_{t=9}^{10}\frac{C_t\big(x_t(O_i),x_t(O_j)\big)}{2} \quad (11)$$

Finally, the total similarity function was composed by the three partial similarities as follows.

$$\beta_{total}(I(O_i),I(O_j)) = \frac{\beta_{endo}+\beta_{meso}+\beta_{ecto}}{3} \quad (12)$$

All similarity functions were bounded in the interval [0, 1], where 0 means there are no similarity (greatest difference) and 1 corresponds to identical somatotypes.

The procedure to calculate the similarity between two somatotypes using the similarity function is described as follows: First, calculate the partial similarity of the three components (β_{endo}, β_{meso}, β_{ecto}) between of somatotypes using the equations (9), (10) and (11) respectively; second, calculate the overall similarity between somatotypes using the equation (12).

3 Results

From the sample of 38 subjects previously classified [4] we selected six: A_1, A_2 with a rating of endomorphic-mesomorph; B_1, B_2 with a rating of mesomorphic-endomorph and C_1, C_2 with a rating of mesomorphic-ectomorph. These somatotypes were placed in the somatochart (Fig. 1). We calculated the similarity between these six somatotypes described in terms of the 10 variables defined by Heath-Carter (Table 2); using three methods: 1) Similarity Function, proposed in this work; 2) Somatotype Dispersion Distance (SDD); and 3) Somatotype Attitudinal Distance (SAD).

First, we calculated the pairwise similarity between somatotypes belonged to the same class in order to show similarity between these somatotypes should be high, and then we calculated the similarity between somatotypes belonged to different classes, whose likeness should be low. As follows it is shown the application of each method in the calculation of the similarity between two different somatotypes.

Table 2. Description of 6 subjects with Heath-Carter 10 variables.

Variable	A_1	A_2	B_1	B_2	C_1	C_2
x_1	10	15	30	32	6	6
x_2	10	11	25	27	7	8
x_3	5	8	23	20	4	4
x_4	0.8	0.8	1.6	1.7	0.8	0.5
x_5	35.5	34.5	33	34	29	30
x_6	37.5	36	33	32	28	29.5
x_9	65	60	80	82	52	51
x_7	8.8	9.2	9	8.8	8.4	8.5
x_8	6	6.5	6.2	6	5.5	5.8
x_{10}	162	165	172	170	167	169

3.1 Similarity Function β (Proposed Method

To illustrate the application of partial and total similarity functions, we calculated the similarity between somatotypes A_1 and B_1. We calculated the partial similarity between endomorphy components of both somatotypes using (9):

$$\beta_{endo}\big(\Omega I(O_{A1}),\Omega I(O_{B1})\big) = 1 - \sum_{t=1,2,3,10} \frac{\left(\frac{|10-30|}{49}+\frac{|10-25|}{33}+\frac{|5-23|}{21}+\frac{|162-172|}{33}\right)}{4} = 0.49$$

Using (10) and (11), partial similarity between mesomorphy and ectomorphy components respectively was calculated.

$$\beta_{meso}\big(\Omega I(O_{A1}),\Omega I(O_{B1})\big) = 1 - \sum_{t=3}^{8} \frac{C_t\big(x_t(O_i),x_t(O_j)\big)}{6} = 0.73$$

$$\beta_{ecto}\big(\Omega I(O_{A1}),\Omega I(O_{B1})\big) = 1 - \sum_{t=9}^{10} \frac{C_t\big(x_t(O_i),x_t(O_j)\big)}{2} = 0.74$$

Using (12) the overall similarity between the two somatotypes was calculated:

$$\beta_{total}(I(O_{A1}),I(O_{B1})) = \frac{(0.49)+(0.73)+(0.74)}{3} = 0.65$$

3.2 Somatotype dispersion distance (SDD) and Somatotype attitudinal distance (SAD)

For calculating SDD between both somatotypes A_1 and B_1 it was necessary to calculate the three components (endomorphy, mesomorphy, ectomorphy) for each somatotype and then, the X, Y coordinates. This is illustrated following the next procedure:

1. Calculate parameter x:
x_{A1} = [(10+10+5)170.18]/162 = 26.26, $(x_{A1})^2$ = 689.58, $(x_{A1})^3$ = 18108.57

2. Calculate endomorphy component using (1):
Endomorphy$_{A1}$= -0.72 + 0.15(26.26) - 0.0007(689.57) + 0.0000014(18108.57)
Endomorphy$_{A1}$= 15.68
Endomorphy$_{B1}$= 7.32

3. For calculating mesomorphy component, we identify the equivalence among the parameters used in equation (2) and variables in Table 2. So the equivalence is: U=x_8, F=x_7, B=x_6-x_5, P=x_4 and H=x_{10}, then:
Mesomorphy$_{A1}$= 0.86(6) + 0.6(8.8) + 0.19(2) + 0.16(0.8) - 0.13(162) + 4.5
Mesomorphy$_{A1}$= -5.77
Mesomorphy$_{B1}$= -10.34

4. Ectomorphy component needs to calculate the HWR (height-weight ratio) by equation (3). For both somatotypes:
$HWR_{A1} = \frac{162}{\sqrt[3]{65}} = 40.5$, $HWR_{B1} = \frac{172}{\sqrt[3]{80}} = 40$

If 38.28<HWR<40.75, then ectomorphy = (HWR*0.463) –17.63, then:
Ectomorphy$_{A1}$ = [40.5(0.463)] –17.63 = 1.12

$\text{Ectomorphy}_{B1} = 0.89$

5. Calculate coordinates X and Y using equations (4) and (5) respectively:
$X_{A1} = 1.12\text{-}2.77 = \text{-}1.65$, $X_{B1} = \text{-}6.43$
$Y_{A1} = 2(\text{-}5.77) – (2.77\text{-}1.12) = \text{-}15.43$, $Y_{B1} = \text{-}28.89$

6. Calculate SDD using (6):

$$SDD_{A1-B1} = \sqrt{3(-1.65-(-6.43))^2 + (-15.43-(-28.89))^2} \simeq 15.7$$

7. Calculate SAD using equation (7):

$$SAD_{A1-B1} = \sqrt{\begin{matrix}(2.77_{A1} - 7.32_{B1})^2 + (-5.77_{A1} - (-10.34)_{B1})^2 + \\ +(1.12_{A1} - 0.89_{B1})^2\end{matrix}} \simeq 6.8$$

The similarity result for all cases is shown in Table 3. Clearly it is showed that between somatotypes belong to the same class, the similarity is high ($\beta \geq 0.9$), and in the case of somatotypes belonging to different classes there is a low similarity ($\beta \leq 0.85$). However observe that somatotypes A_1-C_1 obtained a similarity $\beta = 0.84$, this is because even both somatotypes are different in their muscular proportions, both have a thin physique.

On the other hand, the distances *SDD* and *SAD* between somatotypes belonged to the same class are short and in the case of somatotypes belonged to different classes the distances are large. Observe that distance between subjects A_1-B_1 and subjects A_1-C_1 have almost the same value; this means that A_1 is far different from B_1 as from C_1, and this is why their distance is large in both cases. By the other hand, observe pair A_1-A_2 (belong to the same class): both SDD and SAD are shorter, but SAD is 40% shorter than SDD. Moreover, distances are also shorter for both pairs B_1-B_2 and C_1-C_2; but interpretation about these distances is not clear enough.

Related with function β, observe the similarity between these same pairs of somatotypes (A_1-B_1), A_1 is more different than B_1 because of their similarity ($\beta = 0.654$) is lower than similarity between A_1-C_1 ($\beta = 0.84$); meaning the pair (A_1-C_1) have a 20% higher similarity.

Table 3. Results of similarity and both distances SDD and SAD.

	A_1-A_2	B_1-B_2	C_1-C_2	A_1-B_1	B_1-C_1	A_1-C_1
Similarity β	0.91	0.94	0.96	0.65	0.62	0.84
SDD	2.68	0.87	0.96	15.7	15.2	12.7
SAD	1.58	0.38	0.82	6.80	6.55	5.30

5 Conclusion

Calculate the somatotype by the anthropometry method, needs to enter the 10 body measures into the three component rating (endo, meso and ecto-morphy). This rating is plotted on a two-dimensional somatochart, previously calculating coordinates X, Y by using the three components. These component ratings are used also in the equations for two and three-dimensional distances between somatotypes, called the somatotype dispersion distance (SDD) and somatotype attitudinal distance (SAD) respectively. Analysis of the three-number somatotype rating presents the problem of how should such a rating be analyzed. How far (near) most be the distance between somatotypes, in order to decide which class the somatotype belongs to.

In this sense, the similarity function proposed in this work, offers a new perspective for comparing somatotypes, it does not need the three component rating neither the somatochart. It just uses the 10 body measurements from the individual somatotype description and the similarity function, in order to compare somatotypes. Furthermore, sometimes in biotypological research or sport sciences, it is necessary to analyze one of the three components in a separately way. Our method allows comparing (analyzing) each component in an individual manner by defining the support sets and the partial similarity function. Finally we shown that our method is effective for comparing somatotypes and estimates the similarity between them, and all these characteristics make it simpler than the traditional methods.

5 References

1. Carter, J.E.L.: The Heath-Carter Anthropometric Somatotype Instruction Manual. Department of Exercise and Nutritional Sciences. San Diego State University. USA (2002)
2. Martínez-Trinidad, J.F., Guzmán-Arenas A.: The Logical Combinatorial Approach to Pattern Recognition, An Overview Through Selected Works. Pattern Recogn. 34(4), 741-751 (2001)
3. Ortiz-Posadas, M.R., Vega-Alvarado, L, Toni B,: A Mathematical Function to Evaluate Surgical Complexity of Cleft Lip and Palate. Comput. Meth. Prog. Bio. 94, 232-238 (2009)
4. Acosta-Pineda, I., Ortiz-Posadas, M.R.: Somatotype Classification Using the Logical-Combinatorial Approach (in Spanish). In: V Latin-American Biomedical Engineering Congress, vol. 3, pp.1-4. IFMBE Press, La Habana, Cuba (2011)