APÉNDICE A

ESTUDIO DE LA PRESERVACIÓN DE LA TOPOLOGÍA

En este apéndice se muestra el estudio exhaustivo realizado de la preservación de la topología de los cuatro modelos auto-organizativos introducidos en el punto 2.1, que poseen características de aprendizaje diferentes.

PRODUCTO TOPOGRÁFICO

El producto topográfico (Bauer y Pawelzik, 1992), también llamado en ocasiones "producto wavering" (Pawelzik, 1991), es una buena medida de la preservación de la topología del espacio de entrada por una red auto-organizativa. Esta medida ha sido ampliamente utilizada en la literatura para la comparación de modelos auto-organizativos (Merkl et al., 1994) (Herbin, 1995) (Trautmann y Denoeux, 1995).

La idea principal de esta medida es comparar la relación de vecindad de dos neuronas con respecto a su posición en el mapa por un lado ($Q_2(j,k)$) y según sus vectores de referencia por otro ($Q_1(j,k)$) (Figura A.1):

$$Q_1(j,k) = \frac{d^V\left(w_j, w_{n_k^A(j)}\right)}{d^V\left(w_j, w_{n_k^V(j)}\right)} \qquad \text{(A.1)}$$

$$Q_2(j,k) = \frac{d^A\left(j, n_k^A(j)\right)}{d^A\left(j, n_k^V(j)\right)} \qquad \text{(A.2)}$$

donde j es una neurona, w_j es su vector de referencia, n_K^V indica la k vecina más cercana a j en el espacio de entrada V según una medida de distancia d^V y n_K^A indica la k vecina más cercana a j en la red A según una medida de distancia d^A.

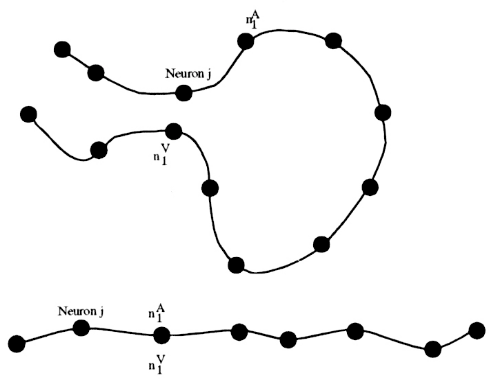

Figura A.1. Vecindades en el espacio de entrada y en la red.

De esta definición, se extrae que $Q_1(j,k)=Q_2(j,k)=1$ sólo si las vecinas más cercanas de orden k en el espacio de entrada y en la red coinciden. Sin embargo, estas medidas son muy sensibles a pequeñas variaciones en el orden de vecindad de las neuronas en ambos espacios. Para ello, se multiplican ambas medidas para todos los órdenes de vecindad k, obteniendo

$$P_1(j,k) = \left(\prod_{l=1}^{k} Q_1(j,l) \right)^{1/k} \tag{A.3}$$

$$P_2(j,k) = \left(\prod_{l=1}^{k} Q_2(j,l) \right)^{1/k} \tag{A.4}$$

y

$$P_3(j,k) = \left(\prod_{l=1}^{k} Q_1(j,l) \cdot Q_2(j,l) \right)^{1/2k} \tag{A.5}$$

En el caso de que la dimensionalidad de la red y del espacio de los vectores de entrada coincidan se tiene que $P_3 = 1$. Cualquier desviación de dicho valor implica una disparidad en la dimensionalidad de ambos espacios.

Para extender esta medida a todas las neuronas de la red y todos los posibles órdenes de vecindad y, dado que sólo estamos interesados en obtener desviaciones de dicha medida de 1, se define el producto topográfico P como

$$P = \frac{1}{N(N-1)} \sum_{j=1}^{N} \sum_{k=1}^{N-1} log\left(P_3(j,k)\right) \tag{A.6}$$

MEDIDA DE LA PRESERVACIÓN DE LA TOPOLOGÍA DE LOS DIFERENTES MODELOS AUTO-ORGANIZATIVOS

Para obtener una medida de la capacidad de preservación de la topología de los diferentes modelos auto-organizativos estudiados se han realizado diversos experimentos, tomando un espacio de entrada bidimensional (imágenes de 320x320 puntos), con diferentes funciones de densidad de probabilidad (Figura A.2). El cuadrado y el círculo son espacios de entrada con una topología similar a la de los mapas auto-organizativos de Kohonen, que son los que poseen una relación de vecindad más restringida de entre todos los modelos; el anillo posee un hueco en su interior, por lo que será difícil que las redes con estructura preestablecida preserven bien su topología; los cuatro cuadros separados representan una función no continua, con lo que sólo aquellas redes con capacidad de división podrán realizar un buen aprendizaje; y la mano es un espacio más complejo de preservar su topología, al tener concavidades y convexidades.

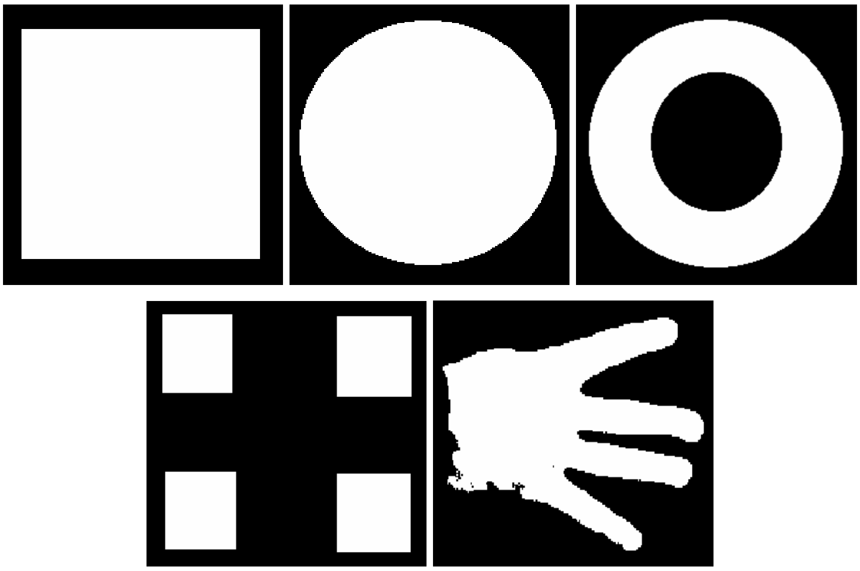

Figura A.2. Espacios de entrada.

Se ha realizado el aprendizaje de estos espacios de entrada con los diferentes modelos auto-organizativos utilizando, para cada uno de ellos, valores en sus parámetros empleados usualmente.

Para el aprendizaje de los mapas auto-organizativos se ha empleado el algoritmo de (Kohonen, 1995) con $t_{max}=100$, $\sigma_i=5$, $\sigma_f=1$, $\alpha_i=0.8$, $\alpha_f=0.1$.

Las Growing Cell Structures se han empleado según (Fritzke, 1993) con los parámetros $\varepsilon_b=0.1$, $\varepsilon_n=0.01$, $\alpha=0$, $\lambda=10000$, $\eta=0$.

Siguiendo el algoritmo mostrado en el punto 2.2.1 se ha educado la Neural Gas con los siguientes parámetros: $t_{max}=100$, $\lambda_0=100$, $\lambda_{t_{max}}=0.01$, $\varepsilon_0=0.5$, $\varepsilon_{t_{max}}=0.005$, $T_0=20$, $T_{t_{max}}=200$.

La Growing Neural Gas empleada sigue el algoritmo del punto 2.2.2 con $\varepsilon_1 = 0.1$, $\varepsilon_2 = 0.01$, $\lambda = 10000$, $\alpha = 0$, $\beta = 0$.

Se ha realizado el aprendizaje de redes que poseen 100 neuronas, educando cinco redes de cada uno de los modelos y para cada uno de los espacios de entrada. Una vez realizado este aprendizaje se ha procedido al cálculo del producto topográfico, con el objetivo de medir la preservación de la topología en cada uno de los casos (Tabla A.1).

A diferencia del uso normal que se hace del producto topográfico en la literatura en la que la distancia en el espacio de entrada d^V es la distancia euclídea entre dos puntos, en este trabajo se emplea la distancia geodésica (Sonka et al., 1998), definida como la longitud del mínimo camino que une ambos puntos dentro del subespacio de entrada determinado por el objeto (Figura A.3). Si no se puede establecer un camino entre ellos, $d^V = \infty$.

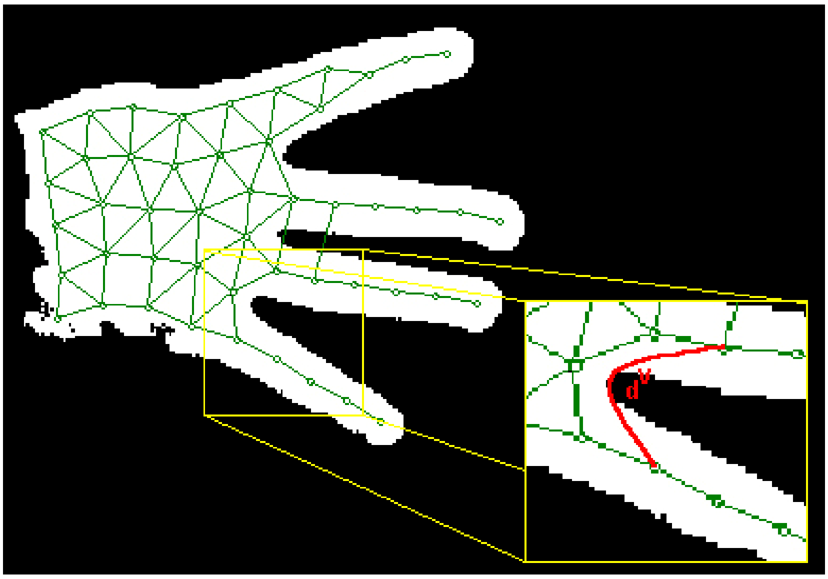

Figura A.3. Distancia geodésica.

Espacio de entrada	Modelo auto-organizativo	Producto topográfico[1]	Error de cuantización
Cuadrado	Kohonen	0.005914	4523614
Cuadrado	Growing Cell Structure	0.015628	1360265
Cuadrado	Neural Gas	0.005175	1176427
Cuadrado	Growing Neural Gas	0.007785	1286321
Círculo	Kohonen	0.004974	3841524
Círculo	Growing Cell Structure	0.015420	1103505
Círculo	Neural Gas	0.005331	954927
Círculo	Growing Neural Gas	0.007832	1039228
Anillo	Kohonen	Indeterminado	4262412
Anillo	Growing Cell Structure	0.017626	1306101
Anillo	Neural Gas	0.003718	1109236
Anillo	Growing Neural Gas	0.005030	1228092
4 cuadros	Kohonen	Indeterminado	7143062
4 cuadros	Growing Cell Structure	0.006417	1342739
4 cuadros	Neural Gas	0.002889	1123384
4 cuadros	Growing Neural Gas	0.004221	1276545
Mano	Kohonen	0.036150	8657777
Mano	Growing Cell Structure	0.021125	1939797
Mano	Neural Gas	0.003539	1556044
Mano	Growing Neural Gas	0.00607	1756100

Tabla A.1. Cálculo de la preservación de la topología (100 neuronas).

[1] El valor “Indeterminado” del producto topográfico es debido a que alguna neurona se encuentra fuera del espacio de entrada y, por tanto, no se puede calcular la distancia de ésta a cualquier otra neurona.

Como se puede observar las redes que mejor preservan la topología de los espacios de entrada son aquellas cuya topología no está definida a priori, sino que se adapta con el aprendizaje: las Neural Gas y las Growing Neural Gas. Sólo en aquellos casos en los que el espacio de entrada tiene una estructura similar a la topología predefinida de los mapas auto-organizativos, el producto topográfico es similar al de los otros modelos. Esto es debido a que en el cálculo del producto topográfico únicamente se considera la topología de la red, ya que se considera que se ha realizado un correcto aprendizaje del espacio de entrada y que, por tanto, preservará la topología del mismo. Sin embargo, en estos casos no es así, ya que los mapas de Kohonen caracterizan peor el espacio de entrada al producirse un mayor error de cuantización (Kohonen, 1995), calculado como:

$$E = \sum_{\forall \xi \in V} \left\| w_{\phi_w(\xi)} - \xi \right\|^2 \cdot p(\xi) \qquad \text{(A.7)}$$

Las Neural Gas y las Growing Neural Gas tienen un comportamiento similar ante diferentes espacios de entrada, sin embargo, la complejidad del aprendizaje de las Neural Gas es muy superior al de las Growing Neural Gas, debido al proceso de ordenación de todos los vectores de referencia para cada uno de los patrones de entrada ξ (paso 3 del aprendizaje), obteniendo unos tiempos de aprendizaje muy superiores (Tabla A.2).

Modelo auto-organizativo	**Tiempo de aprendizaje (segundos)**
Kohonen	38
Growing Cell Structure	9
Neural Gas	117
Growing Neural Gas	12

Tabla A.2. Tiempos de aprendizaje de los diferentes modelos auto-organizativos.

En la Tabla A.3 se representa el producto topográfico de las Neural Gas si se interrumpiera su aprendizaje a los 12 segundos, que es el tiempo en el que finalizan su aprendizaje las Growing Neural Gas. Como se observa, los resultados tanto en la preservación de la topología como en el error de cuantización son bastante peores, ya que no es capaz, en ese tiempo, de finalizar el proceso de adaptación.

Espacio de entrada	Modelo auto-organizativo	Producto topográfico	Error de cuantización
Cuadrado	Neural Gas	0.089522	39323868
Cuadrado	Growing Neural Gas	0.007785	1286321
Círculo	Neural Gas	0.075313	30155116
Círculo	Growing Neural Gas	0.007832	1039228
Anillo	Neural Gas	Indeterminado	37848968
Anillo	Growing Neural Gas	0.005030	1228092
4 cuadros	Neural Gas	Indeterminado	101925872
4 cuadros	Growing Neural Gas	0.004221	1276545
Mano	Neural Gas	Indeterminado	62578424
Mano	Growing Neural Gas	0.00607	1756100

Tabla A.3. Preservación de la topología de la Neural Gas deteniendo su aprendizaje a los 12 segundos.

Sin embargo, si se modifican los parámetros de la NG, por ejemplo el número de patrones de entrada por iteración λ, para que finalice su adaptación en esos 12 segundos, los resultados del producto topográfico se siguen manteniendo cercanos a los conseguidos con la GNG.

Espacio de entrada	Modelo auto-organizativo	Producto topográfico	Error de cuantización
Cuadrado	Neural Gas	0.006390	1210058
Cuadrado	Growing Neural Gas	0.007785	1286321
Círculo	Neural Gas	0.006207	974271
Círculo	Growing Neural Gas	0.007832	1039228
Anillo	Neural Gas	0.003454	1150331
Anillo	Growing Neural Gas	0.005030	1228092
4 cuadros	Neural Gas	0.003690	1194841
4 cuadros	Growing Neural Gas	0.004221	1276545
Mano	Neural Gas	0.005739	1668036
Mano	Growing Neural Gas	0.00607	1756100

Tabla A.4. Preservación de la topología de la Neural Gas modificando sus parámetros para que finalice a los 12 segundos.

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