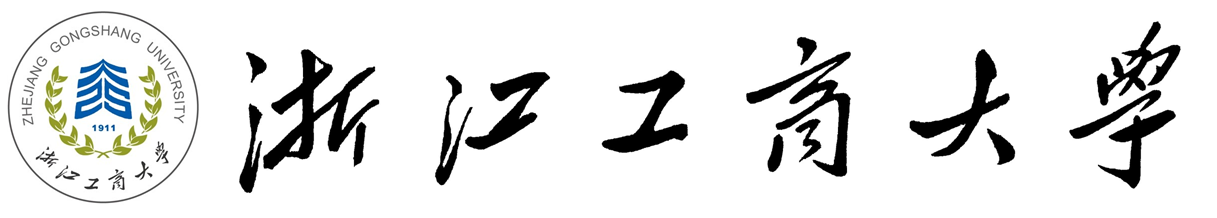
ÃÜ¼¶£º¹«¿ª ÖÐÍ¼·ÖÀàºÅ£ºO212.1



1.0

**Ë¶Ê¿Ñ§Î»ÂÛÎÄ**

**ÂÛÎÄÌâÄ¿£º»ùÓÚDA-EM¸Ä½øËã·¨µÄÓÐÏÞ»ìºÏÄ£ÐÍ²ÎÊý¹À¼Æ**

**×÷ÕßÐÕÃû£ºÑîÊ¥½Ü**

**Ñ§¿Æ×¨Òµ£ºÍ³¼ÆÑ§**

**ÑÐ¾¿·½Ïò£º  ÊýÀíÍ³¼Æ**

**Ö¸µ¼½ÌÊ¦£ºÍõÎ°¸Õ**

**Ìá½»ÈÕÆÚ£º2020 Äê1ÔÂ**

**ÕªÒª**

1.5 ´óÊý¾Ý±³¾°ÏÂ, ºÜ¶àÊý¾ÝÍùÍùÀ´×Ô²»Í¬µÄ·Ö×é. ÓÉÓÚÄÜ½ÏºÃ¿Ì»­ÕâÖÖÒìÖÊÐÔ,ÓÐÏÞ»ìºÏÄ£ÐÍÊÜµ½ÁËÍ³¼ÆÑ§½çºÍ¼ÆËã»ú½çµÄÖØÊÓ. ¶ÔÓÐÏÞ»ìºÏÄ£ÐÍÖÐµÄÊýÀíÎÊÌâ½øÐÐÑÐ¾¿, ÊÇºÜ¶àÓ¦ÓÃÕ¹¿ªµÄÊ×ÒªÈÎÎñ.ÆäÖÐ, Ó¦ÓÃ×î¹ã·ºµÄÊÇ¸ßË¹»ìºÏÄ£ÐÍ. ±¾ÎÄÔòÖ÷ÒªÑÐ¾¿¸ßË¹»ìºÏÄ£ÐÍµÄ²ÎÊý¹À¼ÆÎÊÌâ.

1.5 Ïà½ÏÓÚ¾­µäEMËã·¨, È·¶¨ÐÔÍË»ðÆÚÍû×î´ó»¯Ëã·¨(Deterministic annealing expectation-maximization algorithm, DA-EMËã·¨)ÒýÈëÁËÍË»ð²ÎÊý, ÓÐÐ§½â¾öÁËÒþ±äÁ¿µÄºóÑé¸ÅÂÊ¹À¼Æ¹ý¶ÈÒÀÀµ²ÎÊý³õÊ¼ÖµµÄÎÊÌâ. È»¶øÊ¹ÓÃ¹ýÐ¡µÄÍË»ð²ÎÊý³õÊ¼Öµ¼«Ò×µ¼ÖÂDA-EM Ëã·¨ÊÕÁ²µ½ÎÈ¶¨µã¶øÊ¹µü´ú¹ýÔçÍ£Ö¹. ¶ÔÓÚ´ËÎÊÌâ, ÓÐÑ§ÕßÌá³öÁË»ùÓÚJacobian¾ØÕó·ÖÎöÑ¡ÔñÍË»ð²ÎÊýÀíÂÛÏÂ½çµÄ·½·¨, µ«¸Ã·½·¨ÈÔ²»ÄÜÍêÈ«±ÜÃâÄ£ÐÍ¾ùÖµÏòÁ¿µÄÖØºÏ.

1.5 Õë¶ÔÉÏÊöÎÊÌâ, ±¾ÎÄÌá³öÒ»ÖÖ¸Ä½øµÄDA-EMËã·¨. ÔÚ¸ø¶¨ÍË»ð²ÎÊýÀíÂÛÏÂ½çµÄDA-EMËã·¨»ù´¡ÉÏ, ¸ÃËã·¨Í¨¹ýÒýÈëÁ½¸ö³Í·£Ïî, ·Ö±ð¶Ô»ìºÏ±ÈÀýºÍÄ£ÐÍ²ÎÊýµÄ¾àÀëÊ©ÒÔ³Í·£À´ÐÞ¸Ä¶ÔÊýËÆÈ»º¯Êý. Ä£ÄâÊý¾ÝºÍÕæÊµÊý¾ÝµÄÊµÑé½á¹û¾ù±íÃ÷: ÔÚÒ»¶¨Ìõ¼þÏÂ, ¸Ä½øµÄDA-EMËã·¨¶Ô¸ßË¹»ìºÏÄ£ÐÍµÄ²ÎÊý¹À¼ÆÐ§¹û¸ü¼Ó×¼È·ºÍÎÈ¶¨, ²¢ÇÒÆäÊÕÁ²ËÙ¶ÈÒ²¿ìÓÚDA-EMËã·¨.

**Abstract**

1.5 In the context of big data, many data often come from different groups. The finite mixture model is highly regarded by the statistics and computer industry because of describing this heterogeneity very well. There are lots of researches on mathematical problems in finite mixture models. The first task of application deployment. Gaussian mixture model is the most widely used among them. Naturally, this paper mainly studies the parameter estimation problem of Gaussian mixture model.

1.5 Compared with the classical EM algorithm, the Deterministic annealing expectation-maximization algorithm (DA-EM algorithm) introduces annealing parameters. However, using the initial value of the annealing parameter too small can easily cause the DA-EM algorithm to converge to a stable point and cause the iteration to stop prematurely. To solve this problem, some scholars proposed a method based on Jacobian matrix analysis to select the theoretically lower bound of the annealing parameter, but this method still cannot completely avoid the coincidence of the model mean vector.

1.5 Aiming at the above problems, this paper proposes an modified DA-EM algorithm. On the basis of the DA-EM algorithm given the theoretically lower bound of the annealing parameter, the method modifies the log likelihood function by introducing two penalty terms and penalizing the mixture ratio and the distance of the model parameters. At the same time, the method maintains the convergence of the original algorithm. The experimental results of the simulated data and the real data show that: Under certain conditions, the modified DA-EM algorithm estimates the parameters of the Gaussian mixture model. The effect is more accurate and stable, and its convergence speed is faster than DA-EM algorithm.

1.8 [0pt]

# ÒýÑÔ

## ÑÐ¾¿±³¾°¼°ÏÖ×´

### Ñ¡Ìâ±³¾°

Ëæ×Åµç×Ó¼ÆËã»ú¼°»¥ÁªÍøµÄÑ¸ËÙ·¢Õ¹, ÓÐÏÞ»ìºÏÄ£ÐÍµÄÇ±Á¦ºÍÓ¦ÓÃ¼ÛÖµµÃµ½ÁË¸÷½çµÄ¹ã·ºÈÏ¿É. »ìºÏÄ£ÐÍÒÑ¾­±»Ó¦ÓÃµ½Éç»á¿ÆÑ§¡¢¾­¼ÃÑ§¡¢ÌìÎÄÑ§¡¢ÒÅ´«Ñ§¡¢ÉúÎïÑ§µÈÁìÓò, ÊÇÉú´æ·ÖÎö¡¢Ä£Ê½Ê¶±ð¡¢¾ÛÀàÅÐ±ð¡¢Ç±ÔÚ±äÁ¿·ÖÎöµÈÍ³¼Æ·½·¨µÄÑÐ¾¿ÍÁÈÀ. ÕâÐ©ÐÐÒµ¶¼³öÏÖÁËº£Á¿¡¢¸´ÔÓ¡¢¸ßÎ³¶ÈµÄÊý¾Ý, Ò»°ãµÄµ¥Ò»·Ö²¼ÎÞ·¨ÔÚÆäÖÐÍÚ¾ò³öÓÐÓÃµÄÐÅÏ¢, ¶ø»ìºÏÄ£ÐÍÔòÄÜÓÐÐ§µØ½â¾öÕâ¸öÎÊÌâ. ÓÐÏÞ»ìºÏÄ£ÐÍ×÷ÎªÒ»ÖÖ±ãÀûµÄ, °ë²ÎÊý·½·¨¾ßÓÐºÜÇ¿µÄÁé»îÐÔ. ²»Í¬ÀàÐÍµÄ»ìºÏÄ£ÐÍÊÊÓÃÓÚ²»Í¬µÄÁìÓò: Ö¸Êý»ìºÏÄ£ÐÍÊÊÓÃÓÚ¹¤³ÌÁìÓò; ²´ËÉ»ìºÏÄ£ÐÍÊÊÓÃÓÚÒ½Ñ§ÁìÓò; ¶ø¸ßË¹»ìºÏÄ£ÐÍµÄÊÊÓÃ·¶Î§×î¹ã. ÒòÎªÔÚÑù±¾Á¿×ã¹»´óµÄÇ°ÌáÏÂ, ÈÎÒâÒ»¸ö·Ö²¼¶¼¿ÉÒÔÓÃÈô¸É¸ö¸ßË¹·Ö²¼È¥±Æ½ü.

È»¶ø, ²»Í¬ÓÚ´«Í³µÄµ¥Ò»·Ö²¼Ä£ÐÍ, ÓÐÏÞ»ìºÏÄ£ÐÍµÄ²ÎÊý¹À¼ÆÎÊÌâµÄ´¦Àí·½Ê½½ÏÎª¸´ÔÓ. ¼«´óËÆÈ»¹À¼Æ(MLE)×÷Îª¾­µäµÄ²ÎÊý¹À¼Æ·½·¨, ÔÚ»ìºÏÄ£ÐÍÀï²»ÄÜÖ±½ÓµÃµ½½âÎö½â. Òò´Ë, ÈËÃÇ¶Ô»ìºÏÄ£ÐÍ²ÎÊý¹À¼ÆµÄÔçÆÚÑÐ¾¿·½·¨»¹Í£ÁôÔÚ¾Ø·½·¨ÉÏ, µ«ÓÉÓÚ¾Ø·½·¨µÄ¼ÆËã¹ýÓÚ¸´ÔÓ(ÔÚ¸ßÎ¬Êý¾ÝÉÏÓÈÎªÃ÷ÏÔ), Õâµ¼ÖÂ»ìºÏÄ£ÐÍµÄÑÐ¾¿½øÕ¹Ê®·Ö»ºÂý. ¶ø¼ÆËã»úµÄ³öÏÖ´òÆÆÁËÕâÒ»ÏÖ×´. 1972Äê, TanºÍRobertson¿ªÊ¼Ê¹ÓÃ¼«´óËÆÈ»·¨(ML)×ö¸ßË¹»ìºÏÄ£ÐÍµÄ²ÎÊý¹À¼Æ, ²¢´ÓÀíÂÛÉÏÖ¤Ã÷ÁË¸Ã·½·¨ÓÅÓÚ¾Ø·½·¨. ½ô½Ó×Å, Dempster(1977)Ìá³öÁËEMËã·¨ÓÃÓÚ¼ÆËãÓÐÏÞ»ìºÏÄ£ÐÍµÄ¼«´óËÆÈ»¹À¼Æ, ´ó·ù½µµÍÁË²ÎÊý¹À¼ÆµÄ¼ÆËãÁ¿, ÕâÒ²½øÒ»²½ÎªÓÐÏÞ»ìºÏÄ£ÐÍµÄÍÆ¹ãºÍÓ¦ÓÃµì¶¨ÁË»ù´¡.

ÓÐÏÞ»ìºÏÄ£ÐÍ×Ô19ÊÀ¼ÍÄ©±»Ìá³öÒÔÀ´, ¾­¹ýÊýÑ§¼Ò, Í³¼ÆÑ§¼ÒµÈ¶ÔÆäÀíÂÛ»ù´¡¡¢Ó¦ÓÃËã·¨µÄÉîÈëÑÐ¾¿, ÒÑ³ÉÎªÓÐÐ§ÄâºÏ¸´ÔÓÃÜ¶ÈµÄ½¨Ä£¹¤¾ß. »ìºÏÄ£ÐÍµÄ»ù±¾½á¹¹¼òµ¥, µ«Æä·Ö²¼Ïàµ±Áé»î. ²ÎÊý¹À¼ÆºÍÄ£ÐÍÑ¡Ôñ×÷Îª»ù´¡¹¤×÷, È´ÊÇºÜ¶àÑÐ¾¿Õ¹¿ªµÄÊ×ÒªÈÎÎñ, Òò´Ë¾ßÓÐÖØÒªµÄÀíÂÛÒâÒå. ¾¡¹ÜEMËã·¨½â¾öÁË¼«´óËÆÈ»·½·¨Ã»ÓÐ½âÎö½âµÄÎÊÌâ, ÇÒÏà¹Ø¶¨½×·½·¨ÔÚÒ»¶¨³Ì¶ÈÉÏ·ÀÖ¹ÁË¹ýÄâºÏ, µ«ÒÀ¾É´æÔÚÊÕÁ²ËÙ¶È¹ýÂý¡¢Ð§¹û²»ÎÈ¶¨¡¢ÊýÖµÇó½âËã·¨¸´ÔÓµÈÎÊÌâ. ±¾ÎÄ¶ÔÓÐÏÞ»ìºÏÄ£ÐÍµÄ²ÎÊý¹À¼Æ¼°¶¨½×½øÐÐÑÐ¾¿, ÄÜ½øÒ»²½·á¸»¸ÃÁìÓòÊýÀíÑÐ¾¿µÄÀíÂÛÌåÏµ.

ÓÐÏÞ»ìºÏÄ£ÐÍÓÉÓÚÄÜ¹»¶ÔÒìÖÊÊý¾Ý½øÐÐ½¨Ä£, ÔÚÊ±ÏÂÈÈÃÅµÄÍ¼Ïñ´¦Àí¡¢ÈË¹¤ÖÇÄÜ¡¢Ä£Ê½Ê¶±ðµÈÁìÓòÊÜµ½´óÁ¿Ñ§ÕßµÄ¹Ø×¢. ÌØ±ðµØ, ÔÚÈç½ñµÄ´óÊý¾Ý»·¾³ÏÂ, º£Á¿µÄÑù±¾Êý¾ÝÍùÍùÀ´×ÔºÜ¶àÖÖÀà»ò·Ö×é. ÓÐÏÞ»ìºÏÄ£ÐÍÕýÊÇ¿Ì»­ÕâÖÖÒìÖÊÐÔ(heterogeneity)µÄÓÐÁ¦½¨Ä£¹¤¾ß. ÓÉÓÚÓÐÏÞ»ìºÏÄ£ÐÍµÄ²ÎÊý¹À¼ÆºÍ¶¨½×Îª¾ÛÀàÅÐ±ð¡¢Éú´æ·ÖÎöµÈÍ³¼Æ·½·¨Ìá¹©ÁËÖ§³Å, Ìá¸ßÏà¹ØËã·¨µÄ¼ÆËãËÙ¶È¡¢×¼È·ÐÔºÍÎÈ¶¨ÐÔÓúÏÔÖØÒª; Í¬ÑùµØ, ÌôÑ¡³öÒ»¸öÇ¡µ±ÓÖ¼ò½àÄ£ÐÍÄÜÓÐÐ§½µµÍÄ£ÐÍµÄ¸´ÔÓ¶È. Òò´Ë, ±¾ÎÄÑÐ¾¿ÄÚÈÝ¾ßÓÐÃ÷ÏÔµÄÊµ¼ÊÓ¦ÓÃ¼ÛÖµ, ÄÜ½øÒ»²½´Ù½øÓÐÏÞ»ìºÏÄ£ÐÍÔÚÐí¶à¿ÆÑ§ÁìÓòµÄ·¢Õ¹.

### ÑÐ¾¿ÏÖ×´

EMËã·¨µÄ³öÏÖÎª¸ßË¹»ìºÏÄ£ÐÍ´øÀ´ÁË³¤×ã·¢Õ¹, Æä×ÔÉíÒ²ÒòÎª¼òµ¥ÊµÓÃ¡¢Ò×ÓÚ¼ÆËã»ú±à³ÌµÄÊµÏÖ¡¢Ó¦ÓÃ¹ã·ºµÈÌØµã, ÎüÒýºÜ¶àÑ§Õß¶ÔÆä½øÐÐ´óÁ¿ÑÐ¾¿, ÎªËüµÄÁ¼ºÃÐÔÄÜÌá¹©ÁËÀíÂÛÖ§³Å, ²¢¸ø³öÁËºÜ¶àÖøÃûµÄEMÑÜÉúËã·¨. Cheng(1987)¸ø³öÁËEMËã·¨ÔÚÇúÖ¸Êý´ØÏÂµÄÊÕÁ²³É¹û; XuºÍJordan(1995)Ö¸³öÁËEMËã·¨¾ßÓÐÁ¼ºÃµÄÊÕÁ²ÐÔ, ²¢¸ø³öÁËÊÕÁ²ËÙ¶È; MaºÍFu(2005)Ö¸³öµ±¸ßË¹»ìºÏÄ£ÐÍ¸÷¸ö³É·ÖµÄÖØµþ²¿·Ö×ã¹»Ð¡Ê±, EMËã·¨¿ÉÒÔ¹À¼ÆÄ£ÐÍ²ÎÊýµÄÕæÖµ; Tanner(1990)¶ÔÓÚEMËã·¨²»Ò×ÇóµÃÆÚÍû±í´ïÊ½µÄÇé¿ö, Ìá³öÁË²ÉÓÃ½üËÆ¼ÆËãµÄMCEMËã·¨, µ«ÊÇ¸Ã·½·¨ÒÀÀµ³éÑù, ¹À¼ÆÖµ»áËæ×Åµü´ú´ÎÊýµÄÔö¼ÓÔÚÕæÖµÉÏÏÂ²¨¶¯; ÎªÁË¼Ó¿ìEMËãµÄÊÕÁ²ËÙ¶È, Louis(1982)Ìá³öÁËAtiken¼ÓËÙ·½·¨, Lange(1995)Ìá³öÁËÄâÅ£¶Ù¼ÓËÙ·½·¨; MengºÍRudinÏòEMËã·¨ÖÐ¼ÓÈëËæ»úµÄË¼Ïë, Ìá³öÁËËæ»úEM(SEM)Ëã·¨(1991), ²¢Í¨¹ý·Ö¿ª¹À¼Æ²ÎÊýµÄ·½Ê½Ìá³öÁËÆÚÍûÌõ¼þ×î´ó»¯(ECM)Ëã·¨(1993); MaºÍGe(2007)Í¨¹ýÑÐ¾¿»ìºÏÄ£ÐÍµÄ¼¸ºÎÐÔÖÊ, ¸ø³öÁËÓÃÓÚÏß×´Ä£Ê½·¢ÏÖµÄ¹ãÒåEMËã·¨.

Ê¹ÓÃ¼«´óËÆÈ»·¨¹À¼Æ¸ßË¹»ìºÏÄ£ÐÍ²ÎÊýµÄÇ°ÌáÊÇ¸ø¶¨Ä£ÐÍµÄ·ÖÖ§Êý, ÔÚÄ£ÐÍ·ÖÖ§ÊýÎ´ÖªµÄÇé¿öÏÂ, ÏëÒª¼ÌÐøÊ¹ÓÃ¼«´óËÆÈ»·¨¹À¼ÆÄ£ÐÍ²ÎÊý, ÔòÐèÒªÑ°ÕÒÆäËûÍ¾¾¶½â¾öÄ£ÐÍÑ¡ÔñµÄÎÊÌâ. ³ýÁËÒ»Ð©¾­µäµÄÄ£ÐÍÑ¡Ôñ·½·¨, Èç: AIC(Akaike, 1973), BIC(Schwarz, 1978). »¹ÓÐÒ»Ð©×¨ÃÅ×÷ÓÃÓÚÓÐÏÞ»ìºÏÄ£ÐÍµÄÄ£ÐÍÑ¡Ôñ·½·¨. Leroux(1992)ÌÖÂÛÁË¾­µäÓÐÏÞ»ìºÏÄ£ÐÍÖÐ»ùÓÚAIC ºÍBICµÄ¶¨½×ÎÊÌâ. ChenºÍKalbfleisch(1996)Ìá³öµÄ³Í·£×îÐ¡¾àÀë·¨, ÕâÖÖ·½·¨Í¨¹ýÒýÈë¹ØÓÚ»ìºÏ±ÈÂÊµÄ³Í·£ÏîÐÞ¸Ä¶ÔÊýËÆÈ»º¯Êý, À´·ÀÖ¹»ìºÏ±ÈÂÊÈ¡Öµ¹ýÐ¡µÄ¹ýÄâºÏÀàÐÍ. µÚÈýÀàÊÇ¼ÙÉè¼ìÑéÀà, ÓÐC()¼ìÑé(NeymanºÍScott, 1966)¡¢ËÆÈ»±È¼ìÑé(GhoshºÍSen, 1985; ChenºÍChen, 2001)¡¢ ¸Ä½øËÆÈ»±È¼ìÑé(ChenµÈ, 2001, 2004; FuµÈ, 2008)¡¢D-¼ìÑé(CharnigoºÍSun, 2004)ºÍEM-¼ìÑé(LiºÍChen, 2004; ChenµÈ, 2012; Chen ºÍLi, 2012; ChenµÈ, 2017); ChenºÍKhalili(2008)Ìá³öµÄ³Í·£ËÆÈ»·½·¨Í¨¹ý¶Ô»ìºÏÂÊºÍ³É·Ö²ÎÊý¾àÀë½øÐÐ³Í·£, ÄÜ¹»Í¬Ê±ÊµÏÖÄ£ÐÍ¶¨½×¼°²ÎÊý¹À¼Æ. KimºÍSeo(2014)ÌÖÂÛÁËÔÚ¶à¸ö¾Ö²¿¼«´óÖµ´æÔÚµÄÇé¿öÏÂ, ¸ßË¹»ìºÏÄ£ÐÍÖÐ³É·Ö¸öÊýµÄ¹À¼Æ. ´ËÍâ, »¹ÓÐPeng(2016)Ìá³öµÄÆÚÍûË®Æ½×¼Ôò(desirability level criterion), Grimm(2017)Ìá³öµÄk-ÕÛ½»²æÑéÖ¤·½·¨µÈ, ¶¼¸øÓÐÏÞ»ìºÏÄ£ÐÍµÄ¶¨½×ÎÊÌâÌá¹©ÁËÐÂµÄ½â¾ö·½°¸.

ËäÈ»EMËã·¨ÐÔÄÜÁ¼ºÃ, µ«Ëü±¾ÉíÒ²´æÔÚ×ÅÒ»Ð©È±ÏÝ, ±ÈÈç: ¶Ô²ÎÊý³õÊ¼Öµ·Ç³£Ãô¸Ð¡¢²»ÄÜÈ·±£ÊÕÁ²µ½È«¾Ö×îÓÅ¡¢ÐèÒªÌáÇ°¸ø¶¨Òþ±äÁ¿µÄËùÓÐ¿ÉÄÜµÄÈ¡ÖµµÈ. Õë¶ÔÕâÐ©È±ÏÝ, ºÜ¶àÑ§Õß¶ÔEMËã·¨½øÐÐÁË¸Ä½ø. ÓÉÓÚEMËã·¨µÄ¹À¼ÆÐ§¹ûÔÚºÜ´ó³Ì¶ÈÉÏÒÀÀµ²ÎÊýµÄ³õÊ¼Öµ, ºÏÊÊµÄ²ÎÊý³õÊ¼Öµ²»½öÄÜ¼Ó¿ìËã·¨µÄÊÕÁ²ËÙ¶È, »¹ÄÜÊ¹µÃËã·¨±ÜÃâÊÕÁ²µ½¾Ö²¿×îÓÅ. Figueiredo(2002)·¢ÏÖEMËã·¨¶Ô³õÖµÃô¸ÐÒÔ¼°²ÎÊý¹À¼ÆÖµ¿ÉÄÜÎ»ÓÚ¿Õ¼ä±ß½çµÈÈ±µã, ¸Ä½øÁËEMËã·¨Í¬Ê±Ö¤Ã÷ÁËEMËã·¨¾ß±¸×ÔÍË»ðÐÔÖÊ; Pal(2002)µÈÌá³öÁËÒ»ÖÖËæ»úEMËã·¨À´´¦Àí²ÎÊý³õÊ¼»¯ÎÊÌâ; ½â¾öEM Ëã·¨Ò×ÓÚÊÕÁ²µ½¾Ö²¿¼«ÖµµÄÁíÒ»Àà·½·¨¾ÍÊÇÈ«¾ÖÐÔËã·¨ÓëEMËã·¨Ïà½áºÏµÄÐÎÊ½, ÈçÁ£×ÓÈºËã·¨(HametnerºÍJakubek, 2010)¡¢ÒÅ´«Ëã·¨(Santos et al, 2017)¡¢ÍË»ðËã·¨(Shah et al, 2014)µÈÊ¹µÃEMËã·¨¾¡Á¿±ÜÃâÊÕÁ²µ½¾Ö²¿×îÓÅ. ÓÉUedaºÍNakano(1998)Ìá³öµÄÈ·¶¨ÐÔÍË»ðËã·¨(DA-EM)½øÒ»²½ÊµÏÖÁËÈ«¾ÖÐÔËã·¨Óë¾­µäEMËã·¨½áºÏµÄ»ù´¡. YuµÈ(2018)Í¨¹ýJacobian¾ØÕóÖ¸³ö±ØÐë´æÔÚÒ»¸öÍË»ð²ÎÊýµÄÀíÂÛÏÂ½ç, DA-EMËã·¨²ÅÄÜÓÐÐ§±ÜÃâÊÕÁ²µ½ÎÈ¶¨µã.

## ±¾ÎÄµÄ´´ÐÂµã

Õë¶ÔDAEMËã·¨´æÔÚÍË»ð²ÎÊý¹ýÐ¡¼«Ò×ÊÕÁ²µ½ÎÈ¶¨µãµÄÈ±ÏÝ, YuµÈ(2018)Í¨¹ý·ÖÎöDAEMËã·¨²î·Ö·½³ÌµÄJacobian¾ØÕóÌá³öÁËÒ»ÖÖÑ¡ÔñDAEM Ëã·¨ÍË»ð²ÎÊýÀíÂÛÏÂ½çµÄ·½·¨. È»¶ø, ´Ë·½·¨ÈÔ´æÔÚÒ»Ð©È±ÏÝ, Èç»ìºÏ±ÈÀýÎ»ÓÚ¿Õ¼ä±ß½çµÄµÚÒ»Àà¹ýÄâºÏÎÊÌâ, ÎÞ·¨ÍêÈ«±ÜÃâ¸÷Ä£ÐÍ¾ùÖµµãµÄÖØºÏÎÊÌâ. Îª´Ë, ±¾ÎÄÌá³öÒ»ÖÖ¸Ä½øµÄDA-EMËã·¨(MDA-EMËã·¨), ¸Ã·½·¨ÔÚ¶ÔÊýËÆÈ»º¯ÊýÉÏ, ÒýÈëÁËÁ½¸ö³Í·£Ïî·Ö±ð¶Ô»ìºÏ±ÈÀýºÍÄ£ÐÍ²ÎÊýµÄ¾àÀë½øÐÐ³Í·£ÓÐÐ§½â¾öÁËÕâÁ½¸öÈ±ÏÝ. Í¨¹ýÄ£ÄâºÍ¶ÔUCIÊý¾Ý¼¯iris½øÐÐÊµÖ¤·ÖÎö±íÃ÷, Ïà±ÈÓÚDA-EMËã·¨, ±¾ÎÄÌá³öµÄËã·¨»ñµÃµÄ²ÎÊý¹À¼Æ¸ü¼Ó×¼È·ºÍÎÈ¶¨, Æäµü´ú´ÎÊýÒ²Ïà¶Ô½ÏÉÙ.

## ±¾ÎÄ×éÖ¯¿ò¼Ü

±¾ÎÄÖ÷ÒªÄÚÈÝ·ÖÎª5ÕÂ, ¾ßÌå×éÖ¯¿ò¼ÜÈçÏÂ:

µÚ1ÕÂÒýÑÔ, Ö÷Òª½éÉÜÁËÓÐÏÞ»ìºÏÄ£ÐÍºÍEMËã·¨µÄÑÐ¾¿±³¾°, ÑÐ¾¿ÏÖ×´, ²¢¼òÒª²ûÊöÁË¸÷ÖÖ¾­µä·½·¨µÄÓÅÈ±µãºÍ±¾ÎÄµÄ´´ÐÂµã.

µÚ2ÕÂ×¼±¸ÖªÊ¶, ²»½ö½éÉÜÁË¸ßË¹»ìºÏÄ£ÐÍ¡¢EMËã·¨¡¢×î´óìØÔ­ÀíÒÔ¼°È·¶¨ÐÔÍË»ðËã·¨µÄ»ù´¡ÖªÊ¶, ¶øÇÒ¸ø³öÁËEMËã·¨ºÍDA-EMËã·¨¹À¼Æ¸ßË¹»ìºÏÄ£ÐÍ²ÎÊýµÄÏêÏ¸²½Öè, ²¢¼òÒªÍÆµ¼ÁËÍË»ð²ÎÊýÏÂ½çµÄÇó½â¹ý³Ì.

µÚ3ÕÂÊ×ÏÈ½éÉÜÁË³Í·£ËÆÈ»·½·¨¼°SCAD·£º¯Êý, È»ºó¶ÔDAEMËã·¨½øÐÐ¸Ä½øÌá³öÁËMDA-EMËã·¨, ²¢¸ø³öÁËMDA-EMËã·¨µÄ¾ßÌå²½ÖèºÍÏêÏ¸µÄÊýÖµÇó½â¹ý³Ì.

µÚ4ÕÂ´ÓÄ£ÄâºÍÊµÖ¤Á½¸ö½Ç¶È,Í¨¹ý¶Ô±ÈÈýÖÖËã·¨(CEM, DA-EM, MDA-EM)µÄ²ÎÊý¹À¼ÆÐ§¹û, ÑéÖ¤ÁËMDA-EMËã·¨µÄÓÅÔ½ÐÔ.

µÚ5ÕÂÊÇ×Ü½áÓëÕ¹Íû, ×Ü½á¸ÅÀ¨±¾ÎÄËùÑÐ¾¿µÄÖ÷ÒªÎÊÌâ¡¢·½·¨¼°³É¹û, ²¢¶ÔÎ´À´µÄÍØÕ¹ÐÔ¹¤×÷½øÐÐ°²ÅÅ.

# ×¼±¸ÖªÊ¶

## ¸ßË¹»ìºÏÄ£ÐÍ

¸ßË¹»ìºÏÄ£ÐÍ(Gaussian Mixture Model, GMM)ÊÇÒ»ÖÖ³£ÓÃµÄ»ù±¾·Ö²¼Îª¸ßË¹·Ö²¼µÄ»ìºÏÃÜ¶ÈÄ£ÐÍ. ËüÏàµ±ÓÚ¶à¸ö¸ßË¹¸ÅÂÊÃÜ¶Èº¯ÊýµÄ¼ÓÈ¨Æ½¾ù, Ã¿¸ö¸ßË¹ÃÜ¶Èº¯Êý±»³ÆÎªÒ»¸ö³É·Ö(»òÕß³ÆÎª·ÖÄ£ÐÍ), ¸÷¸ö³É·ÖµÄ²ÎÊýÏà»¥¶ÀÁ¢. µ±·ÖÄ£ÐÍµÄ¸öÊý×ã¹»´óÊ±, ¸ßË¹»ìºÏÄ£ÐÍ¿ÉÒÔÒÔºÜ¸ßµÄ¾«¶ÈÈ¥±Æ½üÈÎÒâÒ»¸öÁ¬Ðø·Ö²¼, Òò´ËËüÄÜ½ÏºÃµØ¿Ì»­Êý¾ÝµÄ¿Õ¼ä·Ö²¼¼°ÆäÌØÐÔ.

ÏÂÃæ, ¸ø³ö¸ßË¹»ìºÏÄ£ÐÍµÄÏêÏ¸¶¨Òå.

ÔÚ¿Õ¼äÖÐ, Âú×ã¸ßË¹»ìºÏÄ£ÐÍµÄËæ»ú±äÁ¿µÄ¸ÅÂÊÃÜ¶Èº¯ÊýÎª

ÆäÖÐ, ÊÇÃ¿¸ö³É·ÖµÄÈ¨ÖØ, ³ÆÎª"»ìºÏ±ÈÀý", ÇÒÂú×ãÌõ¼þ

ÊÇµÚk¸ö·ÖÄ£ÐÍ. Âú×ã¸ßË¹¸ÅÂÊÃÜ¶Èº¯Êý

¼ÙÉèÑù±¾Êý¾Ý¼¯ÓÉ¸ßË¹»ìºÏÄ£ÐÍ([[1]](#X56a192b7913b04c54574d18c28d46e6395428ab))Éú³É, ¿ÉÒÔÈÏÎª, Ñù±¾µÄ²úÉú¹ý³ÌÎª: Ê×ÏÈÒÀ¾Ý¸ÅÂÊÑ¡ÔñµÚ¸ö³É·Ö, È»ºóÍ¨¹ýµÚ¸ö³É·ÖµÄ¸ÅÂÊÃÜ¶Èº¯ÊýÉú³ÉÑù±¾, ÎÒÃÇ¿ÉÒÔÖ±½Ó¹Û²âµ½Ñù±¾, µ«ÎÞ·¨ÅÐ¶Ï¸ÃÑù±¾¾ßÌåÊÇÓÉÄÄ¸ö·ÖÄ£ÐÍ²úÉúµÄ, Òò´Ë, ¿ÉÒÔ°ÑÑù±¾Êý¾ÝÁ¥ÊôµÄ¸ßË¹»ìºÏ³É·Ö³ÆÎªÒþ±äÁ¿. ¸ÃÒþ±äÁ¿µÄËùÓÐ¿ÉÄÜÈ¡Öµ, ×÷ÎªÑù±¾µÄÒþº¬Àà±ð±ê¼Ç.

ÏÔÈ», ÎÒÃÇ¿ÉÒÔ¿¼ÂÇ²ÉÓÃ¼«´óËÆÈ»·¨¹À¼Æ¸ßË¹»ìºÏÄ£ÐÍµÄ²ÎÊý. µ«ÊÇ, Ëù¹Û²âµ½µÄÑù±¾Êý¾Ý²¢²»°üº¬¸ßË¹»ìºÏ³É·ÖµÄÐÅÏ¢, ´ý¹À²ÎÊý¶ÔÓ¦µÄ¶ÔÊýËÆÈ»º¯ÊýÒ²Ã»ÓÐ½âÎö½â, ËùÒÔÖ±½Ó½øÐÐ¼«´óËÆÈ»²ÎÊý¹À¼Æ·Ç³£À§ÄÑ. Òò´Ë, ¶ÔÓÚ¸ßË¹»ìºÏÄ£ÐÍÎÊÌâµÄÇó½â³£Ê¹ÓÃÆÚÍû×î´ó(Expectation Maximum, EM)Ëã·¨Í¨¹ý²»¶ÏÇó½âÏÂ½çµÄ¼«´ó»¯±Æ½ü¶ÔÊýËÆÈ»º¯Êý¼«´ó»¯µÄ·½Ê½¶Ô²ÎÊý½øÐÐ¹À¼Æ.

## EMËã·¨

µ±¸ÅÂÊÄ£ÐÍÖÐ¼È°üº¬¹Û²â±äÁ¿(¿ÉÒÔÖ±½Ó¹Û²âµÄ±äÁ¿)ÓÖ°üº¬Òþ±äÁ¿(¹Û²â±äÁ¿¶ÔÓ¦µÄÇ±ÔÚ±äÁ¿)Ê±, ¶ÔÓÚ¸ø¶¨µÄÑù±¾, ÎÒÃÇÒÑ¾­²»ÄÜÔÙÖ±½ÓÊ¹ÓÃ¼«´óËÆÈ»·¨»òÕß±´Ò¶Ë¹·¨¹À¼ÆÄ£ÐÍ²ÎÊý. Dempster(1977)Ìá³öÒ»ÖÖµü´úËã·¨–EMËã·¨, Ö÷ÒªÓÃÓÚ´æÔÚÒþ±äÁ¿µÄ¸ÅÂÊÄ£ÐÍ²ÎÊýµÄ¼«´óËÆÈ»¹À¼Æ. ÆäÖ÷ÒªË¼Ïë: °Ñ¼«´ó»¯ËÆÈ»º¯ÊýµÄ¹ý³Ì·Ö½â³É¶à²½µü´ú¹ý³Ì, Í¨¹ýÌõ¼þ²»¶ÏÇó½âÏÂ½çµÄ¼«´ó»¯±Æ½ü¶ÔÊýËÆÈ»º¯Êý¼«´ó»¯µÄ·½·¨¹À¼Æ²ÎÊý. EMËã·¨µÄÃ¿ÂÖµü´ú¿ÉÒÔ·ÖÎªÁ½¸ö²½Öè: E²½, ÀûÓÃÉÏÒ»ÂÖµü´úËù»ñµÄ¹À¼Æ²ÎÊý, ÖØÐÂ¼ÆËãÍêÈ«¶ÔÊýËÆÈ»º¯Êý(°üº¬¹Û²â±äÁ¿ºÍÒþ±äÁ¿µÄ¶ÔÊýËÆÈ»º¯Êý)¹ØÓÚÒþ±äÁ¿µÄÌõ¼þÆÚÍû; M²½, ¼«´ó»¯ÍêÈ«¶ÔÊýËÆÈ»º¯ÊýµÄÌõ¼þÆÚÍû, ¸üÐÂ²ÎÊýµÄ¹À¼ÆÖµ.

¼ÙÉè¿Õ¼äÖÐÓÐ¹Û²â±äÁ¿, Æä¸ÅÂÊÃÜ¶Èº¯ÊýÎª, ÆäÖÐÎªÄ£ÐÍ´ý¹À²ÎÊý; ¿Õ¼äÖÐÓÐ¹Û²â±äÁ¿X¶ÔÓ¦µÄ²»±»¹Û²âµ½µÄ±äÁ¿, ÎªºÍµÄÁªºÏ¸ÅÂÊÃÜ¶Èº¯Êý. ¾ßÌåÀ´Ëµ, ÔÚ¸ßË¹»ìºÏÄ£ÐÍÖÐ, Ëæ»ú±äÁ¿¿ÉÒÔ×÷ÎªÑù±¾ Á¥ÊôµÄ¸ßË¹»ìºÏ³É·Ö, ÎªÑù±¾µÄÒþº¬±ê¼Ç±äÁ¿.

µÄÑù±¾¹Û²âÊý¾Ý¼¯Îª, ³ÆÎª"²»ÍêÈ«Êý¾Ý", Æä¶ÔÓ¦µÄ¶ÔÊýËÆÈ»º¯ÊýÎª. ¶ÔÓ¦µÄÒþ±äÁ¿µÄÑù±¾Êý¾Ý¼¯Îª, ÆäÖÐ, ÊÇÒ»¸ö²»ÄÜ±»Ö±½Ó¹Û²âµÄ±äÁ¿. Èç¹ûÒþ±äÁ¿Ò²±»¹Û²âµ½ÁË, ÄÇÃ´ ³ÆÎª"ÍêÈ«Êý¾Ý".

¶ÔÓÚº¬ÓÐÀëÉ¢Òþ±äÁ¿µÄ¸ÅÂÊÄ£ÐÍ,Òþ±äÁ¿µÄËùÓÐ¿ÉÄÜÈ¡ÖµÎª. ÎÒÃÇÍ¨¹ý¼«´ó»¯¹Û²âÊý¾Ý¹ØÓÚ²ÎÊýµÄ¶ÔÊýËÆÈ»º¯ÊýÀ´¹À¼Æ³É·Ö²ÎÊý, ¼´¼«´ó»¯

ÓÉÓÚ¶ÔÊýËÆÈ»º¯Êý([[2]](#Xa4b9237bacccdf19c0760cab7aec4a8359010b0))ÖÐ°üº¬ÁËÎ´¹Û²âÑù±¾ÒÔ¼°ºÍµÄ¶ÔÊý, Ê¹µÃ¼«´ó»¯¹ý³Ì±äµÃ·Ç³£¸´ÔÓ, Òò´Ë¿¼ÂÇµ½ÁËµü´úµÄ·½Ê½, Öð²½Ôö¼Ó¶ÔÊýËÆÈ»º¯ÊýÒÔ¹À¼Æ²ÎÊý, Õâ±ãÊÇEM Ëã·¨µÄ±¾ÖÊË¼Ïë.

¼ÙÉèµÚtÂÖµü´úºóµÄ²ÎÊý¹À¼ÆÖµÎª, ÎªÁËÈ·±£¶ÔÊýËÆÈ»º¯Êý²»¶ÏÔö¼Ó, ËùµÃµÄÐÂµÄ²ÎÊý¹À¼ÆÖµÐèÒªÂú×ã. Òò´Ë¿¼ÂÇÁ½ÕßÖ®²î

ÀûÓÃJensen²»µÈÊ½¿ÉµÃ

ËùÒÔ, ¼«´ó»¯, Ö»Ðè¼«´ó»¯

´Ó¶ø¿ÉÒÔµÃ³ö

Áî

ÏÂÃæ¸ø³öEMËã·¨µÄ¾ßÌå²½Öè.

Step1: ¸ø¶¨²ÎÊý³õÊ¼Öµ;

Step2(E²½): ÔÚµÚtÂÖµü´úµÃµ½µÄ²ÎÊý¹À¼ÆÖµµÄ»ù´¡ÉÏ, ¼ÆËãº¯Êý (¼ò³Æ, Qº¯Êý)

Step3(M²½): Í¨¹ý×î´ó»¯, »ñµÃµÚÂÖµü´úµÄ²ÎÊý¹À¼ÆÖµ;

Step4: Áî, ÖØ¸´Step2-3, Ö±µ½Qº¯ÊýÊÕÁ²;

ÕâÀï, ÐèÒª¸ø³öEMËã·¨µÄ¼¸µã½âÊÍËµÃ÷:

(1) EMËã·¨µÄµü´ú¹ý³ÌÒÀÀµ²ÎÊýµÄ³õÊ¼Öµ(µü´ú×î³õµÄ²ÎÊýÖµ), Òò´ËÔÚºÜ´ó³Ì¶ÈÉÏ, ²ÎÊý³õÊ¼Öµ¾ö¶¨ÁËEMËã·¨²ÎÊý¹À¼ÆµÄÐ§¹û¡¢µü´úÂ·¾¶ºÍ´ÎÊý.

(2) EMËã·¨ÖÐµÄÃ¿Ò»ÂÖµü´ú¶¼»áÊ¹Ôö¼Ó»òÕß´ïµ½¾Ö²¿¼«Öµ, Ò²¾ÍÊÇËµEMËã·¨²»ÄÜ±£Ö¤ÕÒµ½È«¾Ö×îÓÅÖµ;

(3) Qº¯ÊýÊÕÁ²Ò»°ãÊÇÖ¸, ¶ÔÓÚ½ÏÐ¡µÄÕý³£Êý,ÈôQº¯ÊýÂú×ã

ÔòÍ£Ö¹µü´ú, Ëã·¨´ïµ½ÊÕÁ².

ÁíÍâ, EMËã·¨µÄÊÕÁ²ÐÔÓÉÒÔÏÂ¶¨ÀíÌá¹©Ö§³ÖºÍ±£Ö¤.

**Theorem 2.1**. *¼ÙÉèÎª¹Û²âÊý¾ÝµÄ¶ÔÊýËÆÈ»º¯Êý, ÎªEMËã·¨µÃµ½µÄ²ÎÊý¹À¼ÆÐòÁÐ, Îª¶ÔÓ¦µÄ¶ÔÊýËÆÈ»º¯ÊýÐòÁÐ.*

*(1) Èô¶ÔÊýËÆÈ»º¯Êý´æÔÚÉÏ½ç, ÄÇÃ´ÊÕÁ²µ½Ä³Ò»Öµ;*

*(2) ÔÚº¯ÊýºÍÂú×ãÒ»¶¨µÄÌõ¼þÏÂ,Í¨¹ýEMËã·¨µÃµ½µÄ²ÎÊý¹À¼ÆÐòÁÐµÄÊÕÁ²ÖµÊÇ¶ÔÊýËÆÈ»º¯ÊýµÄÎÈ¶¨µã.*

¶¨Àí2.1ÖÐµÄ(1)ÌåÏÖÁËEMËã·¨¹ØÓÚ¶ÔÊýËÆÈ»º¯ÊýÐòÁÐµÄÊÕÁ²ÐÔ,(2)ÌåÏÖ¿´EMËã·¨¹ØÓÚ²ÎÊý¹À¼ÆÐòÁÐµÄÊÕÁ²ÐÔ,Ç°Õß²¢²»ÔÌº¬ºóÕß.³ý´ËÖ®Íâ, ¶¨ÀíÖ»ÄÜ±£Ö¤²ÎÊý¹À¼ÆÐòÁÐÊÕÁ²µ½¶ÔÊýËÆÈ»º¯ÊýÐòÁÐµÄÎÈ¶¨µã, ²¢²»ÄÜ±£Ö¤ÊÕÁ²µ½×î´óÖµµã. »»¾ä»°Ëµ, EMËã·¨µü´úµÃµ½µÄ²ÎÊý¹À¼ÆÖµÖ»ÄÜ±£Ö¤ÊÇ¾Ö²¿×îÓÅµÄ, ²¢²»ÄÜÈ·±£ÊÇÈ«¾Ö×îÓÅ. Òò´ËÔÚÓ¦ÓÃ¹ý³ÌÖÐ, Ò»°ãÑ¡È¡¼¸¸ö²»Í¬µÄ³õÊ¼Öµ½øÐÐµü´ú, È»ºóÍ¨¹ý±È½Ï¶ÔÓ¦µÄ¶ÔÊýËÆÈ»º¯ÊýµÄ´óÐ¡Ñ¡Ôñ×îÓÅµÄ²ÎÊý¹À¼ÆÖµ.

### »ùÓÚEMËã·¨µÄ¸ßË¹»ìºÏÄ£ÐÍ²ÎÊý¹À¼Æ

±¾½Ú½«EMËã·¨Ó¦ÓÃµ½¸ßË¹»ìºÏÄ£ÐÍ²ÎÊý¹À¼ÆÎÊÌâÖÐ. ÑØÓÃÇ°ÎÄµÄ·ûºÅ¶¨Òå, ÎÒÃÇ¼ÙÉèÊý¾Ý¼¯ÖÐµÄÑù±¾Îª¶ÀÁ¢Í¬·Ö²¼Ñù±¾, ÇÒ¶¼ÊÇ´ÓÍ¬Ò»¸ö¸ßË¹»ìºÏÄ£ÐÍÖÐ²úÉú

Ê×ÏÈ, ¶ÔÓÚ¸ßË¹»ìºÏÄ£ÐÍ, ÎÒÃÇÊ¹ÓÃ¼«´óËÆÈ»·¨¹¹Ôì¶ÔÊýËÆÈ»º¯Êý

È»ºóÔÙÊ¹ÓÃEMËã·¨¹À¼Æ¸ßË¹»ìºÏÄ£ÐÍµÄ²ÎÊý.

Step1: ¸ø¶¨²ÎÊý³õÊ¼Öµ.

Step2(E²½): ÁîÎª¾­¹ýµÚÂÖµü´úµÃµ½µÄ²ÎÊý¹À¼ÆÖµ, µÚµü´ú¹ý³ÌÖÐQº¯Êý Îª

ÁîºóÑé¸ÅÂÊ, Í¨¹ý±´Ò¶Ë¹¹«Ê½¼ÆËãµÃ³ö

Step3(M²½): ×î´ó»¯Ê½([[4]](#Xb6453892473a467d07372d45eb05abc2031647a)), µÃµ½µÚÂÖµü´úµÄ²ÎÊý¹À¼ÆÖµµÄ¸üÐÂ¹«Ê½.

(1) Çó½âµÄ¸üÐÂ¹«Ê½.

¶ÔÊ½([[4]](#Xb6453892473a467d07372d45eb05abc2031647a))¹ØÓÚÇóÆ«µ¼, ²¢ÇÒÁîÆ«µ¼Îª,µÃµ½

Çó½âÊ½([[6]](#X1dfd96eea8cc2b62785275bca38ac261256e278))¿ÉÒÔµÃ³öµÄ¸üÐÂ¹«Ê½

(2) Çó½âµÄ¸üÐÂ¹«Ê½.

¶ÔÊ½([[4]](#Xb6453892473a467d07372d45eb05abc2031647a))¹ØÓÚÇóÆ«µ¼, ²¢ÇÒÁîÆ«µ¼Îª, µÃµ½

½«Ê½([[7]](#X02ba3cda1883801594b6e1b452790cc53948fda))´úÈëÊ½([[8]](#Xe5dbbcea5ce7e2988b8c69bcfdfde8904aabc1f)), ²¢¼ÆËãµÃ³ö µÄ¸üÐÂ¹«Ê½

(3) Çó½âµÄ¸üÐÂ¹«Ê½.

ÓÉÓÚÂú×ãÌõ¼þ, ¿ÉÒÔÀûÓÃÀ­¸ñÀÊÈÕ³Ë×Ó·¨, ÒýÈëÀ­¸ñÀÊÈÕ³Ë×Ó, ¶ÔQº¯Êý([[4]](#Xb6453892473a467d07372d45eb05abc2031647a))¹¹ÔìÀ­¸ñÀÊÈÕº¯Êý

¶ÔÊ½([[10]](#X1d5781111d84f7b3fe45a0852e59758cd7a87e5))¹ØÓÚÇóÆ«µ¼Îª0, ¿ÉÒÔµÃ³ö

½«Ê½([[11]](#X7ba0791499db908433b80f37c5fbc89b870084b))´úÈë, ¿ÉÒÔµÃµ½

½«Ê½([[12]](#Xb52009b64fd0a2a49e6d8a939753077792b0554))´úÈëÊ½([[11]](#X7ba0791499db908433b80f37c5fbc89b870084b)), µÃµ½ µÄ¸üÐÂ¹«Ê½

Step4: Áî, ÖØ¸´²½ÖèStep2-3, Ê¹ÓÃÊ½([[13]](#Xd307a3ec329e10a2cff8fb87480823da114f8f4))¡¢([[7]](#X02ba3cda1883801594b6e1b452790cc53948fda))¡¢([[9]](#Xade7c2cf97f75d009975f4d720d1fa6c19f4897))¸üÐÂ²ÎÊý¹À¼ÆÖµ, Ö±µ½Ëã·¨ÊÕÁ²,¼´Qº¯Êý([[4]](#Xb6453892473a467d07372d45eb05abc2031647a)) ÊÕÁ².

## È·¶¨ÐÔÍË»ðEMËã·¨

EMËã·¨ÊÇÒ»ÖÖµü´ú·½·¨, µü´úµÄ½á¹û½Ï´ó³Ì¶ÈÉÏÒÀÀµÓÚ²ÎÊý³õÊ¼Öµ, ²¢ÇÒÖ»ÄÜ±£Ö¤ÊÕÁ²µ½¾Ö²¿×îÓÅÖµ. ÎªÁË¸ÄÉÆEMËã·¨µÄÕâÒ»ÏµÍ³ÐÔÈ±ÏÝ, UedaµÈ(1998)Ìá³öÁËÈ·¶¨ÐÔÍË»ðEMËã·¨(DA-EM). DA-EMËã·¨ÔÚ¾­µäEMËã·¨ÖÐÒýÈëÁËÍË»ð»úÖÆ, DA-EMËã·¨ÔÚÃ¿¸öÍË»ð²ÎÊýÖµÏÂ¶¼¿ÉÒÔÕÒµ½¾Ö²¿×îÓÅÖµ, ²¢ÔÚÍË»ð²ÎÊý»ºÂýÔö¼ÓµÄ¹ý³ÌÖÐ, Ê¹ÓÃÉÏÒ»´Îµü´úµÃµ½µÄ¾Ö²¿×îÓÅµÄ²ÎÊýÖµ×÷ÎªÐÂµÄËã·¨µü´úµÄ³õÊ¼Öµ½øÐÐÐÂÒ»ÂÖµÄµü´ú. Ïà½Ï¾­µäEMËã·¨, ÔÚÒ»¶¨Ìõ¼þÏÂ, DA-EMËã·¨¿ÉÒÔÒÔ¸ü¸ßµÄ¸ÅÂÊÊÕÁ²µ½È«¾Ö×îÓÅÖµ.

### ×î´óìØÔ­Àí

Ê®¾ÅÊÀ¼ÍÖÐÒ¶, ClausiusÊ×´ÎÌá³öÁË"ìØ"Õâ¸ö¸ÅÄî, ²¢½«Æä¶¨ÒåÎªÎïÀíÏµµÄÄÚ²¿×´Ì¬µÄ²ÎÁ¿, À´±íÊ¾ÏµÍ³ÄÚ²¿µÄ»ìÂÒ³Ì¶È. ìØÔ½´ó, Ôò±íÊ¾ÏµÍ³ÄÚ²¿Ô½»ìÂÒ.ÔÚ¿¨Åµ¶¨Àí»ù´¡ÉÏ, ClausiusÓÚ1850ÄêÌá³öÁËÈÈÁ¦Ñ§µÚ¶þ¶¨ÂÉ(ìØÔö¶¨ÂÉ), ËüÖ¸³öÒ»¸ö¶ÀÁ¢ÏµÍ³µÄ»ìÂÒ³Ì¶È»áÖð½¥Ôö´ó, Ö±µ½Ëü´ïµ½×î»ìÂÒ(ìØ×î´ó)µÄ×´Ì¬. ´ËÊ±ÏµÍ³ÄÚ²¿´ïµ½Æ½ºâÌ¬.

¹ýÁË½«½üÒ»¸öÊÀ¼Í, Shannon(1948)Ìá³öÁËÐÅÏ¢ÂÛ, ÒýÈëÁËìØµÄ¸ÅÄî, ´Ó¸ÅÂÊÂÛµÄ½Ç¶È¶¨ÒåÁË"ÐÅÏ¢ìØ", ²¢¸ø³öÁË¼ÆËã¹«Ê½. ÉèÁ¬ÐøÐÍËæ»ú±äÁ¿µÄ¸ÅÂÊÃÜ¶Èº¯ÊýÎª, ×÷ÓÃÇø¼äÎª, ÔòÐÅÏ¢ìØµÄ¼ÆËã¹«Ê½Îª

ÆäÖÐ, kÎªÕý³£Êý.

¼ÙÉèÎªÀëÉ¢ÐÍËæ»ú±äÁ¿, ÆäËùÓÐ¿ÉÄÜµÄÈ¡ÖµÎª, ÁîÈ¡ÖµÎªµÄ¸ÅÂÊ Îª, ÔòìØµÄ¼ÆËã¹«Ê½Îª

×÷Îª¶ÈÁ¿Ëæ»úÊÂ¼þ²»È·¶¨ÐÔµÄ±ê×¼: ÐÅÏ¢ìØ, ÆäÖµÔ½´ó±íÊ¾ÐÅÏ¢Á¿Ô½ÉÙ. µ±Ëæ»ú±äÁ¿·þ´Ó¾ùÔÈ·Ö²¼Ê±, ÐÅÏ¢ìØ´ïµ½×î´ó. ÕâÈÃìØµÄ¸ÅÄî²»ÔÙ¾ÖÏÞÓÚÈÈÁ¦Ñ§¶øÊÇ¿ÉÒÔÓë¸ÅÂÊÍ³¼ÆÑ§¹ØÁªÆðÀ´, Ó¦ÓÃµ½ÊýÑ§¸÷ÁìÓòÖ®ÖÐ.

Ëæ»ú±äÁ¿µÄ¸ÅÂÊ·Ö²¼¿ÉÒÔ¼ÆËãìØ, ÄÇÃ´, ÓÉËæ»ú±äÁ¿µÄìØ, ÊÇ·ñ¿ÉÒÔÀ´ÇóÆä¸ÅÂÊ·Ö²¼º¯ÊýÄØ? ¸ù¾Ý´ËÏë·¨ÒÔ¼°ÈÈÁ¦Ñ§µÄìØÔö¶¨ÂÉ, Jaynes(1957)Ìá³öÁË×î´óìØÔ­Àí, ²¢ÎªÕýÌ¬·Ö²¼¡¢Ö¸Êý·Ö²¼¡¢¼¸ºÎ·Ö²¼µÈ¶àÖÖ³£ÓÃ¸ÅÂÊÃÜ¶Èº¯ÊýÌá¹©ÁËÀíÂÛ»ù´¡ºÍ¹ý³ÌÍÆµ¼, Ê¹ìØÔ­Àí×ß³öÁËÈÈÁ¦Ñ§, ×ß½øÁËÍ³¼ÆµÄ´óÃÅ.

×î´óìØÔ­ÀíµÄºËÐÄË¼Ïë: ÔÚÍÆ¶ÏËæ»ú±äÁ¿µÄ¸ÅÂÊ·Ö²¼Ê±, ³ä·Ö¿¼ÂÇÒÑÖªÐÅÏ¢(Í¨³£ÎªËæ»ú±äÁ¿º¯ÊýµÄÆÚÍû), ÇÒ²»¶ÔÈÎºÎÎ´ÖªÐÅÏ¢×÷ÈËÎª¼ÙÉè. ÐÅÏ¢µÄÔö¼Ó»áÒýÆðÐÅÏ¢ìØµÄ¼õÉÙ. Òò´Ë, ÔÚÒÑÓÐµÄÐÅÏ¢Ìõ¼þÔ¼ÊøÏÂ, ÁîìØ×î´óµÄ¸ÅÂÊ·Ö²¼Ëù°üº¬µÄÎ´ÖªÐÅÏ¢µÄ¼ÙÉè×îÉÙ, ´Ë¸ÅÂÊ·Ö²¼Ò²¾Í×î·ûºÏÊµ¼Ê. »ùÓÚ×î´óìØÔ­ÀíµÃµ½µÄ¸ÅÂÊ·Ö²¼, ÊÇÔÚÂú×ãÒÑÖªÐÅÏ¢»ù´¡ÉÏ, ¶ÔËùÒÔÎ´ÖªÐÅÏ¢¶¼×öÁË¾ùÔÈ¼ÙÉèµÄÌõ¼þ, µÃµ½µÄÎ¨Ò»"ÎÞÆ«"·Ö²¼.

½ÓÏÂÀ´ÑØÓÃÉÏÎÄ¶¨ÒåµÄ·ûºÅ, ÏÂÃæ¸ø³ö¹ØÓÚÀëÉ¢ÐÍËæ»ú±äÁ¿µÄ×î´óìØÔ­ÀíµÄÊýÑ§±íÊ¾, Á¬ÐøÐÍËæ»ú±äÁ¿×ÔÐÐÀàÍÆ. ¼ÙÉèËæ»ú±äÁ¿ ·þ´Óm¸öÔ¼ÊøÌõ¼þ: ,. ÆäÖÐ, ÎªËæ»ú±äÁ¿µÄº¯Êý, ÎªµÄÆÚÍû, Îª³£Êý. Ôò»ùÓÚÕâÐ©Ô¼ÊøÌõ¼þµÄ×î´óìØÔ­ÀíÎª

### È·¶¨ÐÔÍË»ðËã·¨

ÒºÌåÁ£×ÓÅÅÁÐÎÞÐò, ÀäÈ´ÎïÌåÊ±Ëæ×ÅÎÂ¶ÈµÄ»ºÂýÏÂ½µ, Á£×ÓµÄÈÈÔË¶¯¼õÉÙ, Á£×ÓÔË¶¯Öð½¥Ç÷ÓÚÓÐÐò. µ±ÎÂ¶È½µÖÁÄý½áÎÂ¶ÈÊ±, Á£×ÓÔË¶¯±äÎªÎ§ÈÆ¾§Ìå¸ñµãµÄÎ¢Ð¡Õð¶¯, ´ïµ½½ÏÓÐÐòµÄ½á¾§Ì¬.

¸ù¾ÝBoltzmanÓÐÐòÐÔÔ­Àí¿ÉÖª, µ±ÎÂ¶È½µµÍÊ±, ·â±ÕÏµÍ³ÔÚÃ¿¸öÎÂ¶ÈÏÂ´ïµ½Æ½ºâÌ¬µÄ¹ý³Ì×ñÑ­ÈÈÁ¦Ñ§¶¨ÂÉ¡ª¡ª¶ÔÓÚÓëÖÜÎ§»·¾³½»»»ÈÈÁ¿¶øÎÂ¶È±£³Ö²»±äµÄ·â±ÕÏµÍ³, ÏµÍ³×´Ì¬×ÜÊÇ³¯×Å×ÔÓÉÄÜ¼õÉÙµÄ·½Ïò×Ô·¢½øÐÐ. µ±×ÔÓÉÄÜ´ïµ½×îÐ¡ÖµÊ±, ÏµÍ³´ïµ½Æ½ºâ. ÏµÍ³µÄ×ÔÓÉÄÜº¯Êý¿ÉÒÔ±íÊ¾Îª, ÆäÖÐE±íÊ¾ÏµÍ³ÄÜÁ¿, T±íÊ¾ÏµÍ³ÎÂ¶È, S±íÊ¾ÏµÍ³µÄìØ. ËùÒÔÔÚÄ³Ò»¹Ì¶¨ÎÂ¶ÈÏÂ, ÏµÍ³×´Ì¬ÊÇÏµÍ³ÄÜÁ¿ºÍÏµÍ³ìØÏà»¥¾ºÕùµÄ½á¹û. ÔÚÎÂ¶È½Ï¸ßÊ±, ÏµÍ³ìØSµÄÈ¨ÖØ½Ï´ó, ÏµÍ³Ç÷ÓÚìØÔö´óµÄ·½Ïò, Á£×Ó½ÏÎªÎÞÐò. µ±ÎÂ¶È½ÏµÍÊ±, ÏµÍ³ìØSµÄÈ¨ÖØ±äÐ¡¶øÊ¹µÃÏµÍ³ÄÜÁ¿EµÄÈ¨ÖØÔö´ó, ÏµÍ³×´Ì¬Ç÷ÓÚÄÜÁ¿¼õÐ¡µÄ·½Ïò, Á£×ÓÕûÌå½ÏÎªÓÐÐò.

¸ù¾ÝÍ³¼ÆÁ¦Ñ§, ÁîZ±íÊ¾ÏµÍ³×´Ì¬±äÁ¿, E±íÊ¾ÏµÍ³ÄÜÁ¿±äÁ¿, ·â±ÕÏµÍ³´¦ÓÚ×´Ì¬k, ÏµÍ³ÄÜÁ¿ÎªÊ±µÄ¸ÅÂÊ·Ö²¼ÎªGibbs·Ö²¼

ÆäÖÐ,KÎªÏµÍ³×´Ì¬Êý, Îª·ÖÅäº¯Êý, ÎªBoltzman³£Êý, TÎªÏµÍ³ÎÂ¶È.

µ±Ê±, ÏµÍ³´¦ÓÚËùÓÐ×´Ì¬µÄ¸ÅÂÊÏàÍ¬, Gibbs·Ö²¼ÍË»¯³É¾ùÔÈ·Ö²¼; µ±Ê±, ÏµÍ³Ëù´¦×´Ì¬µÄÄÜÁ¿Ô½µÍ, Æä´¦ÓÚ¸Ã×´Ì¬µÄ¸ÅÂÊÔ½´ó, ¼´ÏµÍ³´¦ÓÚÄÜÁ¿½ÏµÍ×´Ì¬µÄ¸ÅÂÊ½Ï¸ß; µ±Ê±, ÏµÍ³´¦ÓÚÄÜÁ¿×îµÍÊ±µÄ×´Ì¬.

¸ù¾ÝÍË»ð¹ý³Ì, È·¶¨ÐÔÍË»ð¼¼Êõ½«ÐèÒªÇó½âµÄ¼«Ð¡ÖµÎÊÌâ×ª»¯ÎªÏµÍ³ÄÜÁ¿, ÆäÖÐÎª¼«Ð¡ÖµÎÊÌâµÄ´ø¹À²ÎÊý. ¹¹ÔìÏµÍ³ÄÜÁ¿E¶ÔÓ¦µØÂú×ãÒÔÏÂÌõ¼þµÄ×ÔÓÉÄÜº¯Êý:

(1)µ±Ê±, ¹ØÓÚµÄÈ«¾Ö¼«Ð¡ÖµÈÝÒ×Çó³ö;

(2)µ±Ê±, .

È·¶¨ÐÔÍË»ð¼¼ÊõÀûÓÃÎÊÌâÇó½â¹ý³ÌÓëÎïÀíÍË»ð¹ý³ÌµÄÏàËÆÐÔ, ½«Çó½â¼«Ð¡ÖµµÄÎÊÌâ×ª»¯Îª×ÔÓÉÄÜº¯Êý¼«Ð¡»¯ÎÊÌâ. È·¶¨ÐÔÍË»ð¼¼Êõ, ÒÔÏµÍ³ÔÚÉÏÒ»ÎÂ¶ÈÏÂ×ÔÓÉÄÜº¯ÊýµÄ¼«Ð¡µã×÷Îª³õÖµµã, Í¨¹ýÇó½âÏÂÒ»ÎÂ¶È(¸üµÍÎÂ¶È)µÄ×ÔÓÉÄÜº¯Êý¼«Ð¡ÖµÔÚÄ£ÄâÏµÍ³´ïµ½Æ½ºâÌ¬µÄ¹ý³Ì.

¸ù¾ÝÉÏÊö·ÖÎö, ÏÂÃæ¸ø³öÈ·¶¨ÐÔÍË»ðËã·¨µÄ¾ßÌå²½Öè:

Step1: Áî, È¡³õÊ¼ÎÂ¶È×ã¹»´ó, ÔÚ´ËÎÂ¶ÈÏÂ, ×ÔÓÉÄÜº¯Êý¶ÔÓ¦µÄ²ÎÊý¹À¼ÆÖµÈÝÒ×Çó³ö;

Step2: ½µµÍÎÂ¶È, Áî, ÆäÖÐ, ÔÚµÃµ½µÄÇ°ÌáÏÂ, Çó½â×ÔÓÉÄÜº¯Êý, µÃµ½, È»ºóÁî;

Step3:ÖØ¸´²½ÖèStep2, Ö±µ½, ÇÒ²ÎÊý¹À¼ÆÖµÊÕÁ².

### »ùÓÚDA-EMËã·¨µÄ¸ßË¹»ìºÏÄ£ÐÍ²ÎÊý¹À¼Æ

ÔÚEMËã·¨ÖÐ, ºóÑé¸ÅÂÊÃÜ¶Èº¯ÊýÔÚ²ÎÊý¹À¼ÆÖÐÆðµ½ÁË¹Ø¼ü×÷ÓÃ, µ«ÊÇËüÔÚµü´úµÄ³õÆÚÊÇ²»¿É¿¿µÄ, ÓÈÆäÊÇ¸ø¶¨µÄ²ÎÊý³õÊ¼Öµ´ó·ùÆ«ÀëÕæÊµÖµÊ±. Òò´ËEMËã·¨ÈÝÒ×ÊÕÁ²µ½¾Ö²¿×îÓÅ, ¶øDA-EMËã·¨½áºÏEMËã·¨ÓëÈ·¶¨ÐÔÍË»ð¼¼Êõ, ÒÔ¸ÄÉÆEMËã·¨ÒÀÀµ³õÊ¼ÖµµÄÈ±ÏÝ.

DA-EMËã·¨ÖÐÒýÈëÍË»ð²ÎÊýÀ´Ä£ÄâÍË»ð¹ý³ÌÖÐÎÂ¶ÈµÄ±ä»¯. Ò»°ã¶øÑÔ, ÎÂ¶ÈµÈÓÚÍË»ð²ÎÊýµÄµ¹Êý, ¼´. ÎÂ¶È»ºÂý½µµÍ, ÏàÓ¦µÄ, ÔÚDA-EMËã·¨ÖÐ, ´ÓÒ»¸ö½ÏÐ¡µÄÍË»ð²ÎÊý¿ªÊ¼, Öð½¥Ôö´ó²ÎÊýÖµ.ÎªÁËÈÃ»ºÂýÔö³¤,ÕâÀïÈ¡ µÄÔö³¤±¶ÊýÎª1.01. µ± Ê±, DA-EMËã·¨ÔòÍË»¯³ÉEMËã·¨, Òò´ËEMËã·¨¿ÉÒÔ±»¿´×÷ÊÇDA-EMËã·¨µÄÒ»¸öÌØÀý.²»Í¬ÓÚEMËã·¨, DA-EMËã·¨ÔÚºóÑé¸ÅÂÊµÄ¼ÆËãÉÏÒýÈëÁËÍË»ð²ÎÊý

¶ÔÓÚ¸ßË¹»ìºÏÄ£ÐÍ¶øÑÔ, Èç¹ûÒÑÖª, ÄÇÃ´  µÄ×î´óËÆÈ»¹À¼ÆÓëEMËã·¨ÏàÍ¬

ÔÚDA-EMËã·¨ÖÐ, ÎÒÃÇ½«×î´ó»¯¶ÔÊýËÆÈ»º¯ÊýÎÊÌâ×ª»¯ÎªÇó½â×îÐ¡»¯×ÔÓÉÄÜº¯Êý. Ëã·¨´ÓÒ»¸ö½Ï¸ßµÄÎÂ¶È, Ò²¾ÍÊÇ´Ó½ÏÐ¡µÄÍË»ð²ÎÊý¿ªÊ¼. µ«ÊÇ, ÈôÑ¡È¡µÄÍË»ð²ÎÊý¹ýÐ¡, , Ôò¼ÆËãµÃ³öµÄºóÑé¸ÅÂÊ. »»¾ä»°Ëµ, ËùÓÐµÄÑù±¾Á¥ÊôÓÚËùÓÐÀàµÄ¸ÅÂÊ¶¼ÏàÍ¬. ÔÚÏÂ´Îµü´úÖÐ, ÒòÑù±¾ÐÅÏ¢¶øÒýÆðµÄ¸ÅÂÊ±ä¶¯²»×ãÒÔ¸Ä±ä´øÁËÍË»ð²ÎÊýµÄºóÑé¸ÅÂÊ([[15]](#X1abd670358e036c31296e66b3b66c382ac00812)), ÈÔ½«µÃµ½ÉÏÒ»´ÎµÄµü´ú½á¹û, ´Ó¶øµ¼ÖÂµü´ú¹ý³ÌÌáÇ°½áÊø. Òò´Ë, ÎÒÃÇÔÚËã·¨³õÊ¼»¯½×¶Î, Ñ¡ÔñÒ»¸öºÏÊÊµÄÍË»ð²ÎÊý³õÊ¼ÖµÓÈÎª¹Ø¼ü. È»¶ø, UedaµÈ(1998)µÄÎÄÏ×ÖÐ²¢Ã»ÓÐÀíÂÛ¹¤×÷ÊÇÎ§ÈÆÍË»ð²ÎÊý³õÊ¼»¯Õ¹¿ªµÄ.

**Input:** ¹Û²âÊý¾Ý, ¸ßË¹»ìºÏÄ£ÐÍ,, ³õÊ¼ÍË»ð²ÎÊý,   
**Output:** ¸ßË¹»ìºÏÄ£ÐÍ²ÎÊý

²ÎÊý³õÊ¼Öµ

¡¡¡¡¸ù¾ÝÊ½([[15]](#X1abd670358e036c31296e66b3b66c382ac00812))¼ÆËãºóÑé¸ÅÂÊ, ¼´Ã¿¸ö·ÖÄ£ÐÍ¶Ô¹Û²âÊý¾ÝµÄÏìÓ¦¶È; ¸ù¾ÝÊ½([[16]](#X574bddb75c78a6fd2251d61e2993b5146201319)), ([[17]](#X716d9708d321ffb6a00818614779e779925365c)), ([[18]](#Xe6a55b6b4563e652a23be9d623ca5055c356940))¼ÆËãµ±Ç°»ìºÏÄ£ÐÍµÄ²ÎÊý; ÅÐ¶ÏÁ½´Îµü´úµÄ×î´óËÆÈ»¹À¼Æ²ÎÊý²»ÔÚ±ä»¯, , »òÕßQº¯Êý²»ÔÙ±ä»¯, . ·ñÔò, , ÖØ¸´²½Öè3,4;

## »ùÓÚJacobian¾ØÕóµÄÍË»ð²ÎÊýÏÂ½çÇó½â

±¾½Ú¼òÒª½éÉÜYuµÈ(2018)»ùÓÚÑÅ¸÷±È¾ØÕóµÄDA-EMËã·¨·ÖÎö, ÓÉÓÚÆª·ùÏÞÖÆ, ÎÒÃÇ½«Ö±½Ó¸ø³öÏà¹Ø¶¨Àí½áÂÛ, Ê¡ÂÔÆäÈß³¤µÄÍÆµ¼¹ý³Ì.

Ê×ÏÈ, ÏÈ½éÉÜJacobian¾ØÕó. Jacobian¾ØÕóÊÇº¯ÊýµÄÒ»½×Æ«µ¼ÊýÒÔÒ»¶¨µÄÐÎÊ½ÅÅÁÐ³ÉµÄ¾ØÕó, ÆäÐÐÁÐÊ½³ÆÎªJacobianÐÐÁÐÊ½. ÎÒÃÇ¿¼ÂÇ²ÎÊý¿Õ¼äÎª

ÏÂÃæÇó½âDA-EMËã·¨µÄJacobian¾ØÕó.

¶ÔÓÚ¹Ì¶¨²ÎÊý, ½«DA-EMËã·¨µÄµü´ú¹ý³ÌÖØÐÂÐ´³É²ÎÊýÓ³Éä

ÆäÖÐ,

ÇÒÓëÉÏÎÄÏàÍ¬, ·Ö±ðÎª¸ßË¹»ìºÏÄ£ÐÍµÄ»ìºÏ±ÈÀý¡¢¾ùÖµÏòÁ¿¡¢Ð­·½²î¾ØÕó²ÎÊý, t±íÊ¾µü´ú´ÎÊý. Èç¹ûËã·¨ÊÕÁ²ÖÁ, ÄÇÃ´±ØÐëÂú×ã

µ±, ¸ù¾ÝÊ½([[16]](#X574bddb75c78a6fd2251d61e2993b5146201319)),([[17]](#X716d9708d321ffb6a00818614779e779925365c)),([[18]](#Xe6a55b6b4563e652a23be9d623ca5055c356940))¿ÉµÃ. ÄÇÃ´, DA-EMËã·¨µÄÎ¨Ò»¾ÛÀàÖÐÐÄ¾ÍÊÇÑù±¾µÄ¾ùÖµÏòÁ¿. ¶øÔÚÏÂÒ»´Îµü´úÖÐ, ÈÔ»áµÃµ½ÏàÍ¬½á¹û (Ëã·¨ÈÔÊÕÁ²ÓÚ) , DA-EMËã·¨ÒòÆäµü´úÏÞÖÆÌáÇ°½áÊø, ´Ó¶øµ¼ÖÂ¾ÛÀàÊ§°Ü. ÏÔÈ», ÔÚÊµ¼ÊÓ¦ÓÃ¹ý³ÌÖÐÎÒÃÇÓ¦¸Ã±ÜÃâµÃµ½ÕâÑùµÄ¾ÛÀà½á¹û. Èç¹ûÔÚËã·¨µÄ³õÊ¼½×¶ÎÁî, ÄÇÃ´DA-EM Ëã·¨½«²»¿É±ÜÃâµØÊÕÁ²ÓÚ.

¿¼ÂÇµ½ÎÄÕÂµÄÍêÕûÐÔ¼°¿É¶ÁÐÔ, ÎÒÃÇ¸ø³öÒÔÏÂ¶¨Àí. ¶¨ÀíµÄÖ¤Ã÷²Î¼ûYuµÈ(2018)µÚ190-194Ò³.

**Theorem 2.2**. *, ÄÇÃ´DA-EMËã·¨Jacobian¾ØÕóµÄÔªËØµÈÓÚ ÆäÖÐ*

¶¨Àí2.2¸ø³öÁËDA-EMËã·¨µÄJacobian¾ØÕóµÄÍ¨ÓÃÐÎÊ½. Jacobian¾ØÕóÔÚÄ³Ò»µãµÄÆ×°ë¾¶ÄÜ·´Ó³¸ÃµãµÄÐÔÖÊ: ÈôJacobian¾ØÕóÔÚ¸ÃµãµÄÆ×°ë¾¶, ÔòËµÃ÷Ëã·¨ÔÚ¸ÃµãÊÕÁ². ¸ù¾ÝÊ½(2.25)¿ÉÒÔ¿´³öJacobian¾ØÕóµÄ¼ÆËãÓëÍË»ð²ÎÊýÏà¹Ø. Èç¹ûÍË»ð²ÎÊýÃ»ÓÐºÏÊÊµÄ³õÊ¼Öµ, ÄÇÃ´Ëã·¨¾ÍÓÐ¿ÉÄÜÊÕÁ²ÓÚ. ÎªÁË·ÖÎöËã·¨ÔÚÎÈ¶¨µãµÄJacobian¾ØÕó, ÎÒÃÇÏÈ¶¨Òå¾ØÕó²Ù×÷.

**Definition 2.1**. *¶ÔÓÚÎ¬¶ÈµÄ¾ØÕóM, ¾ÍÊÇ¶Ô¾ØÕóM°´ÁÐµþ¼ÓµÃµ½µÄÏòÁ¿. ¶ÔÓÚ¾ØÕó, ÆäÖÐÊÇ¾ØÕóMµÄÁÐÏòÁ¿,*

**Lemma 2.1**. *DA-EMËã·¨ÔÚµãµÄJacobian¾ØÕóµÄÐÎÊ½ÎªÆäÖÐ*

ÏÂÃæ, ÎÒÃÇ¸ù¾ÝµÃµ½µÄJacobian¾ØÕó¹À¼ÆDA-EMµÄÍË»ð²ÎÊýÏÂ½ç.

ÏÔÈ», DA-EMËã·¨Ó¦±ÜÃâÊÕÁ²µ½µã, »»¾ä»°Ëµ, ÍË»ð²ÎÊýµÄ³õÊ¼ÖµÊ¹µÃDA-EMËã·¨ÔÚµãµÄJacobian¾ØÕóµÄÆ×°ë¾¶´óÓÚµÈÓÚ1. ÕâÑùDA-EMËã·¨²Å²»»áÔÚ³õÊ¼½×¶Î¾ÍÖ±½ÓÊÕÁ²µ½´Ó¶øÊ¹²ÎÊý¹À¼ÆÊ§Ð§.

ÓÉÒýÀí2.1µÃ³ö¶¨Àí2.3.

**Theorem 2.3**. *¼ÇJacobian¾ØÕóÔÚµã  µÄÆ×°ë¾¶Îª,   ²»ÊÇDA-EMËã·¨µÄ½¥½øÎÈ¶¨µãµÄ±ØÒªÌõ¼þÎª.*

ÖÁ´Ë, ÎÒÃÇÒÑ¾­¸ø³öÁËDA-EMËã·¨µÄÍË»ð²ÎÊý³õÊ¼ÖµÏÂ½çµÄ¾ßÌåÇó·¨. ÔÚµÚÈýÕÂÖÐ, ÎÒÃÇ¶¼½«Ê¹ÓÃ¸ù¾ÝJacobian¾ØÕó·ÖÎöËùµÃµÄÍË»ð²ÎÊý³õÊ¼ÖµÏÂ½çÀ´ÍÆµ¼ÓÐ¹ØDA-EMµÄ¸Ä½øËã·¨, ºóÃæÆª·ù²»ÔÙ×¸Êö.

## Ð¡½á

±¾ÕÂÑÐ¾¿ÁË¸ßË¹»ìºÏÄ£ÐÍµÄ²ÎÊý¹À¼ÆÎÊÌâ. Ê×ÏÈ, ÎÒÃÇ½éÉÜÁË¸ßË¹»ìºÏÄ£ÐÍµÄÀíÂÛ. È»ºó½éÉÜÁË¾­µäEMËã·¨µÄÍÆµ¼¼°ÆäÔÚ¸ßË¹»ìºÏÄ£ÐÍ²ÎÊý¹À¼ÆÖÐµÄÓ¦ÓÃ. ÓÉÓÚEMËã·¨Ò×ÊÜ³õÊ¼ÖµµÄÓ°Ïì¶øµ¼ÖÂËã·¨ÊÕÁ²µ½¾Ö²¿×îÓÅµÄÏµÍ³ÐÔÎÊÌâ, ÎÒÃÇÔÚµÚÈýÐ¡½ÚÃèÊöÁË×î´óìØÔ­ÀíÒÔ¼°È·¶¨ÐÔÍË»ðËã·¨, ²¢½éÉÜÁË»ùÓÚDA-EMËã·¨µÄ¸ßË¹»ìºÏÄ£ÐÍ²ÎÊý¹À¼Æ·½·¨. ¶øÓÖÒòÎªÍË»ð²ÎÊý¹ýÐ¡¶øµ¼ÖÂDA-EMËã·¨µÄ³õÊ¼½×¶Îµü´ú¹ýÔçÊÕÁ²µÄÎÊÌâ, ÎÒÃÇ¼òÒª½éÉÜÁËYuµÈ(2018)¹ØÓÚDA-EMËã·¨µÄÍË»ð²ÎÊý³õÊ¼ÖµµÄÀíÂÛÇó½â.

# »ùÓÚ¸Ä½øDA-EMËã·¨µÄÓÐÏÞ»ìºÏÄ£ÐÍ²ÎÊý¹À¼Æ

±¾ÕÂÊ×ÏÈ½éÉÜÁË³Í·£ËÆÈ»·¨ºÍSCAD·£º¯Êý. È»ºó, ÔÚÄ£ÐÍ¸öÊýÒÑÖªµÄÇ°ÌáÏÂ, ±¾ÕÂÍ¨¹ýÒýÈëÁ½¸ö³Í·£Ïî¶ÔDA-EMËã·¨ÖÐµÄ¶ÔÊýËÆÈ»º¯Êý½øÐÐÁËÐÞ¸Ä, ´Ó¶ø¸Ä½øËã·¨Ìá³öÁËMDA-EMËã·¨, ÓÉÓÚÐÂ·½·¨Éæ¼°µ½¶àÔªÏßÐÔ»Ø¹é±äÁ¿Ñ¡ÔñµÄË¼Ïë, ÎÒÃÇÔÚÏÂÎÄÏÈ½éÉÜÏà¹ØµÄÖªÊ¶.

## Ïà¹ØÖªÊ¶

### ³Í·£×îÐ¡¾àÀë·¨

ChenºÍKalbfeisch(1996)ÔÚAIC(Akaike, 1973), BIC(Schwarz, 1978)µÈÐÅÏ¢×¼Ôò·¨Ë¼ÏëÉÏ, Ìá³öÁË³Í·£×îÐ¡¾àÀë·¨(penalized minimum-distance criterion). ÐÅÏ¢×¼Ôò·¨Ö±½Ó¶ÔÄ£ÐÍ²ÎÊý¸öÊý½øÐÐ³Í·£, ¶ø³Í·£×îÐ¡¾àÀë·¨ÔòÊÇ¶Ô»ìºÏ±ÈÀý½øÐÐ³Í·£. ³Í·£×îÐ¡¾àÀë·¨ÖÐµÄ¾àÀëÎª

ÆäÖÐ

ÎªÀÛ¼Æ·Ö²¼º¯Êý, ¼Ç¾­Ñé·Ö²¼º¯ÊýÎª; ±íÊ¾ºÍÁ½¸öº¯ÊýÖ®¼äµÄ¾àÀë. ¹ØÓÚµÄÀý×Ó°üÀ¨:

(1) kolmogrov-Smirnov¾àÀë

(2) Cramer-VonMises¾àÀë

ÓÉÊ½(3-1)¿ÉÒÔ¿´³ö, Èç¹û¹ýÐ¡, ÄÇÃ´¸Ã¾àÀëº¯ÊýµÄÖµ¾Í»áºÜ´ó. Òò´Ë, ¸Ã·½·¨¿ÉÒÔ·ÀÖ¹EMËã·¨µü´úµÄ²ÎÊý´ïµ½²ÎÊý¿Õ¼äµÄ±ß½ç. Ò»°ãÀ´Ëµ, ¸÷¸ö·ÖÄ£ÐÍµÄ»ìºÏ±ÈÀýÓ¦µ±²»»áºÜÐ¡(¶ÔÓÚ±ÈÀýºÜÐ¡µÄÊý¾Ý¿ÉÒÔÖ±½Óµ±×öÒì³£ÖµÀ´´¦Àí). ËùÒÔ, ¶ÔÓÚ¸ø¶¨ÕæÊµµÄK, ÔÚ¶ÔÊýËÆÈ»º¯ÊýÉÏµÄ±ÈÀýÉÏ×öÒ»¶¨µÄÏÞÖÆ(¼ò³Æ±ÈÀý·£)¿ÉÒÔ½µµÍEMËã·¨ÊÕÁ²µ½¾Ö²¿×îÓÅµÄ¸ÅÂÊ. È»¶ø, ¸Ã·½·¨Ö»¿¼ÂÇµ½ÁË¸ßË¹»ìºÏÄ£ÐÍ»ìºÏ±ÈÀýµÄ¹À¼Æ, ²¢Ã»ÓÐ¿¼ÂÇ»ìºÏÄ£ÐÍµÄ·ÖÄ£ÐÍ²ÎÊý(). Òò´ËÎÒÃÇÔÚÏÂÒ»Ð¡½ÚÖÐ¾ßÌåÑÐ¾¿·ÖÄ£ÐÍ²ÎÊýµÄÆäËûÔ¼Êø·½·¨.

### »Ø¹éÄ£ÐÍÖÐµÄ±äÁ¿Ñ¡Ôñ

¿¼ÂÇÏßÐÔ»Ø¹éÄ£ÐÍ

ÆäÖÐÎªÉè¼Æ¾ØÕó, Îª»Ø¹éÏµÊý, ÎªÏàÓ¦±äÁ¿, ÎªÎó²îÏòÁ¿, ÇÒÆä±äÁ¿¶ÀÁ¢Í¬·Ö²¼.

Tibshirani(1996)Ìá³öÁËÒ»ÖÖ¶àÔªÏßÐÔ»Ø¹éÄ£ÐÍµÄ±äÁ¿Ñ¡Ôñ·½·¨, ¼´LASSO. ¸Ã·½·¨ÒÔ×îÐ¡»¯´ø·£º¯ÊýµÄ²Ð²îÆ½·½ºÍÀ´¹À¼Æ»Ø¹éÏµÊý

ÆäÖÐÎª¿Éµ÷²ÎÊý.

ÓÉÓÚLASSO¶ÔËùÓÐ»Ø¹éÏµÊý¶¼²ÉÈ¡ÁËÏàÍ¬³Ì¶ÈµÄ³Í·£, µ¼ÖÂËù¹À¼ÆµÄ²ÎÊýÊµ¼ÊÊÇÓÐÆ«µÄ. Îª´Ë, FanºÍLi(2001)Ìá³öÁËSCAD·½·¨, ¼´

ÆäÖÐ

ChenºÍKhalili(2008)Ìá³öµÄMSCAD·½·¨, °Ñ¶àÔªÏßÐÔ»Ø¹éÄ£ÐÍÖÐSCAD·½·¨µÄ±äÁ¿Ñ¡ÔñË¼ÏëÔËÓÃµ½ÁË»ìºÏÄ£ÐÍµÄ²ÎÊý¹À¼ÆºÍ¶¨½×ÎÊÌâÖÐ. Í¨¹ýÒýÈëÒ»¸ö¹ØÓÚ²ÎÊý¾àÀëµÄ³Í·£º¯Êý, ¶Ô²ÎÊýÏà½üµÄÄ£ÐÍ½øÐÐºÏ²¢, ´Ó¶øµÃµ½Ò»¸ö½ÏµÍÇÒ¸ü½Ó½üÕæÊµµÄ½×ÊýK. ±¾ÎÄ¸ù¾ÝMSCAD·½·¨ÔÚ¶ÔÊýËÆÈ»º¯ÊýÉÏÒýÈëÁ½¸ö³Í·£Ïî, ·Ö±ð¶Ô»ìºÏ±ÈÀýºÍ²ÎÊýÖ®¼äµÄ¾àÀëÊ©¼Ó³Í·£, ¶ÔDA-EMËã·¨½øÐÐÁË¸Ä½ø, Ìá³öÁËMDA-EMËã·¨.

## MDA-EMËã·¨µÄÀíÂÛÓëÊýÖµÇó½â

### MDA-EMËã·¨µÄÀíÂÛ

2.4½ÚÖÐ»ùÓÚJacobian¾ØÕó·ÖÎöµÄDA-EMËã·¨ÊÇÔÚ²»¸Ä±äDA-EMËã·¨Çó½â¹ý³ÌµÄ»ù´¡ÉÏ, ¸ù¾ÝJacobian¾ØÕóµÄÆ×°ë¾¶À´ÅÐ¶ÏDA-EMËã·¨ÔÚÎÈ¶¨µãµÄÊÕÁ²ÐÔ, Í¬Ê±Ò²¸ø³öÁËÍË»ð²ÎÊýµÄÀíÂÛÏÂ½ç. µ«¶¨Àí2.3Ö»¸ø³öÁË±ÜÃâÊÕÁ²µ½ÎÈ¶¨µãµÄ±ØÒªÌõ¼þ, ÈôÖ±½ÓÊ¹ÓÃ¸ÃÍË»ð²ÎÊýµÄÀíÂÛÏÂ½çÈÔÓÐ¸ÅÂÊµ¼ÖÂËã·¨ÊÕÁ²µ½ÎÈ¶¨µã. ÁíÍâ, µ±ÓÐ¶à¸ö·ÖÄ£ÐÍÊ±(), DA-EMËã·¨ËäÈ»Ã»ÓÐÊÕÁ²µ½ÎÈ¶¨µã, µ«ÊÇÈÔ»á³öÏÖ¶à¸ö¾ÛÀàÖÐÐÄÖØµþµÄÇéÐÎ.

ChenºÍKhalili(2008)Ìá³öÁË¸Ä½øµÄSCAD·½·¨(modified SCAD, MSCAD): Í¨¹ý¶Ô»ìºÏ±ÈÀýºÍÄ£ÐÍ²ÎÊýÖ®¼äµÄ¾àÀëÊ©¼Ó³Í·£, ÒÔ¼õÉÙÄ£ÐÍµÄ¸´ÔÓ¶È. ¾ßÌåµØ, ¶ÔÓÚÔ¤ÏÈÉè¶¨µÄK(), ½«¸÷¸ßË¹Ä£ÐÍ²ÎÊý°´´óÐ¡½øÐÐÅÅÐò(ÕâÀïµÄ²ÎÊýÊÇ¸÷¸ö·ÖÄ£ÐÍµÄ¾ùÖµÏòÁ¿). Áî. ¶¨ÒåÈçÏÂ³Í·£ËÆÈ»º¯Êý

ÆäÖÐ

¿Éµ÷²ÎÊý, , . ÄÇÃ´, ÔÚ¿Õ¼ä

ÉÏ¼«´ó»¯³Í·£¶ÔÊýËÆÈ»º¯Êý(3-3), ÄÜÍ¬Ê±¶Ô¸ßË¹»ìºÏÄ£ÐÍ½øÐÐ¶¨¼ÛºÍÄ£ÐÍ²ÎÊý¹À¼Æ. ×¢Òâµ½³Í·£ÏîÊÇÓÉFanºÍLi(2001)Ìá³ö, Ö¼ÔÚ½â¾öÏßÐÔ»Ø¹é·ÖÎöÖÐ±äÁ¿Ñ¡ÔñÎÊÌâ.

ÕâÀï, ÎÒÃÇÓÃÒ»¸öÐÂµÄ³Í·£ÏîÀ´´úÌæ, ¼´

ÐÂµÄ³Í·£Ïî(¼ò³ÆNEW·£)ÓëSCAD·£µÄ²»Í¬Ö®´¦ÔÚÓÚ: SCAD·£ÄÜ³Í·£Ä£ÐÍ²ÎÊýÖ®¼äµÄ¾àÀë½Ï´óµÄ²ÎÊý, µ±²ÎÊý¾àÀë¼õÐ¡Ê±, ·£ËÆÈ»º¯Êý½«»áÔö´ó. Òò´Ë, ÔÚ¼«´ó»¯¹ý³ÌÖÐ, ¼ä¾àºÜÐ¡µÄ²ÎÊý»áÇ÷ÏòÒ»ÖÂ, ²¢Í¨¹ýºÏ²¢²ÎÊýÏàÍ¬µÄÄ£ÐÍÒÔ¼õÐ¡Ä£ÐÍ¸öÊý; NEW·£Ôò¸ÕºÃÏà·´, µ±²ÎÊý¼ä¾à¼õÐ¡Ê±, ·£ËÆÈ»º¯ÊýÖµ½«»á¼õÐ¡, ´Ó¶øÔÚ¼«´ó»¯¹ý³ÌÖÐ¼ä¾àºÜÐ¡µÄ²ÎÊý»áÏà»¥Ô¶Àë±Ë´Ë.

×Ü½áËùÌá³öµÄÐÂ·½·¨: ÎÒÃÇ¶¨Òå³Í·£¶ÔÊýËÆÈ»º¯Êý

ÆäÖÐ¶Ô»ìºÏ±ÈÀý½øÐÐÔ¼Êø, ¶ÔÄ£ÐÍ²ÎÊýÖ®¼äµÄ¾àÀë½øÐÐÔ¼Êø. ÔÚDA-EMËã·¨»ù´¡ÉÏ, ÐÞ¸Ä¶ÔÊýËÆÈ»º¯ÊýÎªÊ½(3-4), ¼´¿ÉÊµÏÖ¸ßË¹»ìºÏÄ£ÐÍµÄ²ÎÊý¹À¼Æ.

### ÊýÖµÇó½â

ÏÂÃæ, ÎÒÃÇ¶ÔDA-EMËã·¨×÷ÊÊµ±ÐÞ¸Ä, ÒÔ¼«´ó»¯³Í·£¶ÔÊýËÆÈ»º¯Êý(3-4).

ÑØÓÃÉÏÎÄµÄ·ûºÅ¶¨Òå, . ¸ø¶¨Ëæ»ú¶ÀÁ¢Ñù±¾, ¶ÔÓ¦µÄÒþ±äÁ¿±íÊ¾Ã¿¸öÑù±¾ËùÊôµÄ·ÖÄ£ÐÍ, ¼´¶ÔÓÚ, ÓÐ, ÆäÖÐÇÒ. ½áºÏ¹Û²â±äÁ¿ºÍÒþ±äÁ¿Éú³ÉµÄÍêÈ«Êý¾Ý  , µÃµ½³Í·£ÍêÈ«¶ÔÊýËÆÈ»º¯Êý

ÆäÖÐ

E²½ÖÐ, ÔÚ¸ø¶¨¹Û²âÑù±¾ºÍµ±Ç°²ÎÊý¹À¼ÆÖµÌõ¼þÏÂ, ¼ÆËã¹ØÓÚµÄÌõ¼þÆÚÍû, ¼´

ÆäÖÐ

ÕâÀïÎªÉÏÎÄÌá¼°µÄÍË»ð²ÎÊý.

M²½ÎªÇó½â. ÔÚÔ¼ÊøÌõ¼þÏÂ, ²ÉÓÃÀ­¸ñÀÊÈÕ³Ë×Ó·¨, ÓÐ

µÃµ½

ÓÉÓÚÔÚ´¦²»¿Éµ¼, ¶ø´«Í³µÄNewton-Raphson·½·¨ÒªÇóÓÐÒ»½×ºÍ¶þ½×µ¼, Òò´Ë²»ÄÜÖ±½ÓÓ¦ÓÃµ½×î´ó»¯Ê½(3-5)ÖÐ. È»¶ø, ¿¼ÂÇµ½ÊÇÎ¨Ò»µÄÆæÒìµã, ¸ù¾ÝFanºÍLi(2001)µÄ½¨Òé, ½«ÒÔ¾Ö²¿¶þ´Î±Æ½üÔÚÃ¿ÂÖÊýÖµµü´úÖÐÌæ»»·£º¯Êý

ÓÚÊÇ, ¶ÔÓÚÄ£ÐÍ²ÎÊýµÄÇó½âµÈÍ¬ÓÚÇó½âÒÔÏÂ·½³Ì×é

½«Ê½(3-10)´úÈëÉÏÊö·½³Ì×é, µÃ³ö

ÕûÀí, ¿ÉµÃ

ÒÔÉÏ·½³Ì×é°üº¬K¸ö·½³Ì, ¿ÉÇó½âK¸öÄ£ÐÍ²ÎÊý. µÄÇó½âÓëÊ½(2-21)µÄÏàÍ¬

ÏÂÃæÎÒÃÇ¸ø³öMDA-EMµÄËã·¨Á÷³Ì

**Input:** ¹Û²âÊý¾Ý, ¸ßË¹»ìºÏÄ£ÐÍ, , ³õÊ¼ÍË»ð²ÎÊý,   
**Output:** ¸ßË¹»ìºÏÄ£ÐÍ²ÎÊý

²ÎÊý³õÊ¼Öµ

¡¡¡¡¸ù¾ÝÊ½(2-15)¼ÆËãºóÑé¸ÅÂÊ, ¼´Ã¿¸ö·ÖÄ£ÐÍ¶Ô¹Û²âÊý¾ÝµÄÏìÓ¦¶È; ¸ù¾ÝÊ½(3-9), (3-11), (3-12)¼ÆËãµ±Ç°»ìºÏÄ£ÐÍµÄ²ÎÊý; ÅÐ¶ÏÁ½´Îµü´úµÄ×î´óËÆÈ»¹À¼Æ²ÎÊý²»ÔÚ±ä»¯, , »òÕßQº¯Êý²»ÔÙ±ä»¯, . ·ñÔò, , ÖØ¸´²½Öè3,4;

ÔÚÊ¹ÓÃËùÌá³öµÄ·½·¨À´½â¾ö²ÎÊý¹À¼ÆÎÊÌâÖ®Ç°, ÎÒÃÇÊ×ÏÈÐèÒªÑ¡Ôñ¿Éµ÷²ÎÊýºÍ. ChenºÍKalbfleisch(2001)½¨ÒéÈç¹û²ÎÊýÔÚÇø¼ä»ò(MÎªÒ»¸ö½Ï´óµÄÕýÊý)ÄÚ, Ò»¸öºÏÊÊµÄÈ¡ÖµÎª. ÕâÀï, ÎÒÃÇ²Î¿¼XuºÍChen(2015)µÄ×ö·¨, Áî, ÆäÖÐ±íÊ¾µÄ¶þ·¶Êý. ¹ØÓÚ·£º¯ÊýÖÐµÄºÍ. Ç°ÕßÎÒÃÇ²ÉÓÃ10-ÕÛ½»²æÑéÖ¤Ñ¡³ö×î¼Ñ²ÎÊý, ¶øºóÕß¿ÉÒÔ¸ù¾ÝBrehentºÍHuang(2011)µÄ½¨Òé, Áîa=3.

## Ð¡½á

±¾ÕÂÑÐ¾¿ÁË»ùÓÚ¸Ä½øDA-EMËã·¨µÄ¸ßË¹»ìºÏÄ£ÐÍ²ÎÊý¹À¼ÆÎÊÌâ. ÔÚµÚÒ»Ð¡½ÚÖÐ, ÎÒÃÇ½éÉÜÁËÓë·£ËÆÈ»·½·¨Ïà¹ØµÄÁ½Àà·½·¨, Ò»ÀàÊÇ»ùÓÚÐÅÏ¢×¼ÔòË¼Ïë¶øÌá³öµÄ³Í·£×îÐ¡¾àÀë·¨, ÁíÒ»ÀàÊÇÖ¼ÔÚ½â¾ö¶àÔªÏßÐÔ»Ø¹é±äÁ¿Ñ¡ÔñÎÊÌâµÄ·½·¨LASSOºÍSCAD. ÔÚµÚ¶þÐ¡½Ú, ÒòÎªYuµÈ(2018)¸ø³ö¹ØÓÚÍË»ð²ÎÊýµÄÀíÂÛÏÂ½ç²¢²»ÄÜºÜºÃµØ±ÜÃâ¶à¸ö¾ÛÀàÖÐÐÄÖØµþµÄÇé¿ö, ±¾ÎÄ¸ù¾ÝMSCAD·½·¨ÔÚËÆÈ»º¯ÊýÉÏ¶Ô²ÎÊý¼äµÄ¾àÀëºÍ»ìºÏ±ÈÀýÊ©¼Ó³Í·£µÄË¼Ïë, ¶ÔDA-EMËã·¨½øÐÐÁË¸Ä½ø, ¸ø³öÁËMDA-EMËã·¨ºÍÊýÖµÇó½â¹ý³Ì.

# ÊýÖµÊµÑé

±¾ÕÂÍ¨¹ýÄ£ÄâÊý¾ÝºÍÕæÊµÊý¾ÝÏà½áºÏµÄ·½Ê½À´ÑéÖ¤MDA-EMËã·¨µÄ²ÎÊý¹À¼ÆÐ§¹û, Ö÷Òª²ÉÓÃ¾ÛÀà×¼È·ÂÊÖ¸±ê. ÐèÒªËµÃ÷µÄÊÇ, ¾ÛÀàÐ§¹ûµÄÅÐ¶ÏÖ¸±êÒ²ÊÇ²Î²î²»ÆëµÄ. Õë¶ÔÍ¬Ò»¾ÛÀà½á¹û, ²»Í¬µÄÖ¸±ê¿ÉÄÜµÃµ½²»Í¬µÄÅÐ¶Ï½á¹û, ²¢ÇÒÄ¿Ç°Ñ§Êõ½çÃ»ÓÐ¹«ÈÏµÄÍ³Ò»ÅÐ¶Ï±ê×¼. ÓÉÓÚÎÄÕÂÖÐËùÓÐÄ£ÄâºÍÊµÖ¤Ê¹ÓÃµÄÑù±¾Êý¾Ý¶¼´øÓÐÕæÊµÀà±ð±êÇ©, Òò´Ë¿ÉÒÔ½«²»Í¬Ëã·¨µÃµ½µÄÑù±¾¾ÛÀà±êÇ©ÓëÑù±¾Êµ¼Ê±êÇ©¶Ô±È, ¼ÆËã³öËã·¨×¼È·¶È, ´Ó¶ø½ÏÎª¿Í¹ÛµØºâÁ¿¸÷¸ö·½·¨µÄ¹À¼ÆÐ§¹û, ¿¼²ì¸÷Ëã·¨²ÎÊý¹À¼ÆµÄÓÐÐ§ÐÔ. ÎªÁË¼õÉÙ¾ÛÀàÖ¸±êµÄ²îÒì¶Ô¾ÛÀàÐ§¹ûÅÐ¶ÏµÄÓ°Ïì, ±¾ÎÄ½«²»º¬Ö÷¹ÛÒòËØµÄ¾ÛÀà×¼È·¶È×÷Îª¾ÛÀàÐ§¹ûµÄÖ÷ÒªÖ¸±ê. ÏÔÈ», ¾ÛÀàµÄ×¼È·¶ÈÔ½¸ß, ¸ÃËã·¨µÄ²ÎÊý¹À¼ÆÔòÔ½ÓÐÐ§. ´ËÍâ, ÓÉÓÚÊýÖµÄ£ÄâºÍÊµÖ¤·ÖÎö¿ÉÒÔ»ñµÃ²ÎÊýµÄÕæÖµ, Òò´Ë±¾ÎÄÔÚ¸Ã²¿·Ö»¹½«¸ø³ö²ÎÊýÕæÖµÓë²ÎÊý¹À¼ÆÖµÖ®¼äµÄ¾àÀë(MSE), À´¸üºÃµØÆÀ¹ÀËã·¨ÐÔÄÜ.

## Ä£ÄâÑÐ¾¿

²Î¿¼YuµÈ(2018)µÄ×ö·¨,ÔÚ¿Õ¼äÉÏ, ±¾½ÚÍ¨¹ýÊýÖµÄ£ÄâµÄ·½Ê½²úÉúÁËÂú×ãÒÔÏÂ¸ßË¹»ìºÏÄ£ÐÍµÄ300¸öÄ£ÄâÊý¾Ý

ÆäÖÐ

Í¬Ê±±£ÁôÃ¿¸öÄ£ÄâÊý¾ÝËùÊôµÄÕæÊµ·ÖÄ£ÐÍ(¸ßË¹»ìºÏ³É·Ö), Ò²¾ÍÊÇËüÃÇµÄÕæÊµÀà±ð±ê¼Ç.

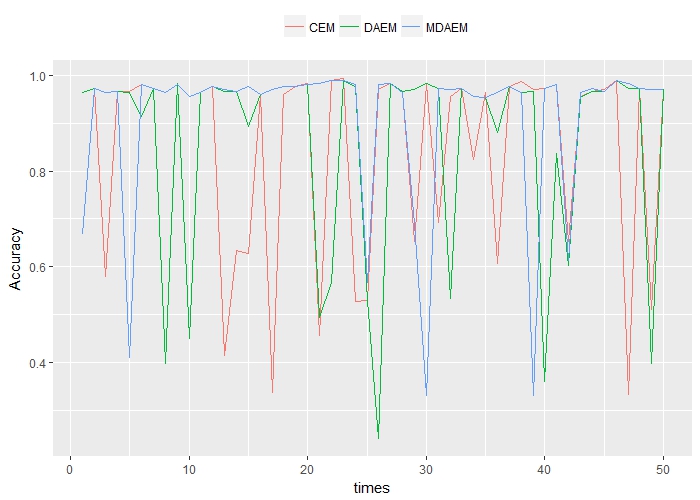
ÏÂÃæ, ·Ö±ðÊ¹ÓÃclassical EM(CEM)Ëã·¨¡¢deterministic annealing EM(DA-EM)Ëã·¨¡¢ÒÔ¼°modified deterministic annealing EM(MDA-EM)Ëã·¨Ä£Äâ²úÉúµÄ·ÂÕæÊý¾Ý(²»º¬ÕæÊµ±êÇ©)¹À¼Æ¸ßË¹»ìºÏÄ£ÐÍµÄ²ÎÊý, ÎªÁË¸üºÃµØ¶Ô±ÈÈýÖÖËã·¨µÄ¾ÛÀàÐ§¹û, ÎÒÃÇÓÃÍ¬Ò»¾ÛÀàÖÐÐÄ¶ÔËã·¨½øÐÐ³õÊ¼»¯: , , , , , ¼ÆËã²»Í¬²ÎÊý¹À¼ÆÖµ¶ÔÓ¦µÄ¾ÛÀà×¼È·ÂÊÒÔ¼°ÆäÓë²ÎÊýÕæÖµµÄ¾àÀë, ÆÀ¹À²ÎÊý¹À¼ÆµÄ×¼È·ÐÔ.

ÓÉÓÚËã·¨µÄ³õÊ¼¾ÛÀàÖÐÐÄÊÇ´ÓÑù±¾Ëæ»úÌôÑ¡µÄ, ÎªÁËÊ¹Ä£ÄâÑÐ¾¿µÄ½á¹û¸üÓÐËµ·þÁ¦, ÎÒÃÇ½øÐÐÁË50´ÎÃÉÌØ¿¨ÂåÄ£Äâ. ÏÂÃæ¸ø³öÒ»ÏµÁÐÍ¼±í×÷Îª½âÊÍ, ÆäÖÐÎÒÃÇÓÃºìÉ«¡¢ÂÌÉ«¡¢À¶É«¶ÔÓ¦±íÊ¾CEMËã·¨¡¢DA-EMËã·¨¡¢MDA-EMËã·¨µÄ¹À¼ÆÐ§¹û.



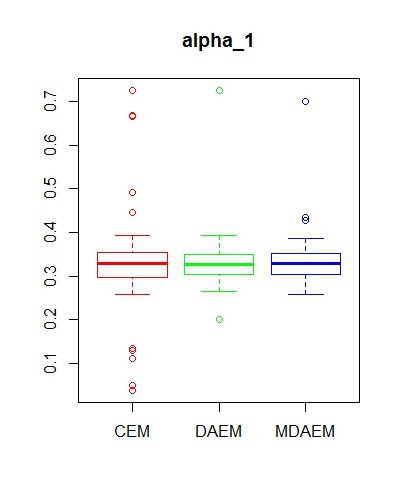
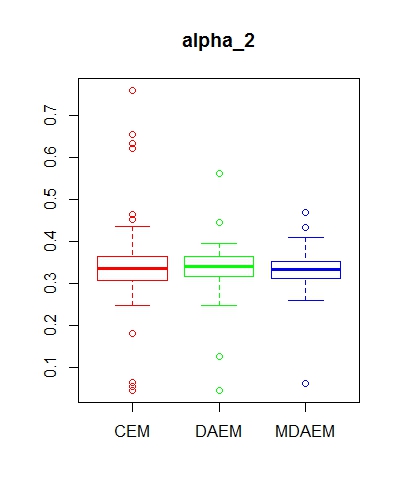
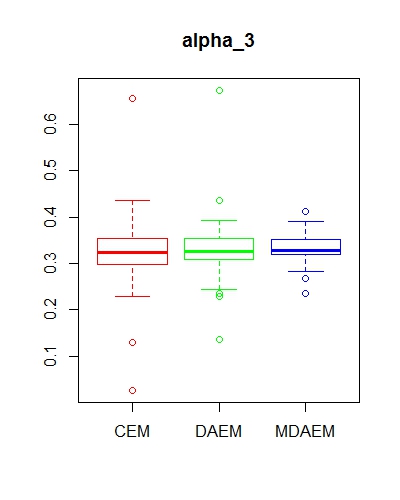
Ê×ÏÈ,ÎÒÃÇÓÃºìÉ«ÊµÏß, ÂÌÉ«ÊµÏß¡¢À¶É«ÊµÏß·Ö±ð±íÊ¾ÈýÖÖËã·¨CEMËã·¨¡¢DA-EMËã·¨¡¢MDA-EMËã·¨µÄ²ÎÊý¹À¼ÆÐ§¹û. ´ÓÍ¼[[f1]](#f1)¿ÉÒÔ¿´³öCEMËã·¨´ó¸ÅÓÐµÄÊµÑé¾ÛÀà×¼È·¶ÈµÍÓÚ, DA-EMËã·¨´óÔ¼ÓÐµÄµÄÊµÑé¾ÛÀà×¼È·¶ÈµÍÓÚ, ¶ø´ú±íMDA-EMËã·¨µÄÀ¶É«ÊµÏß»ù±¾¶¼ÔÚÆäÓàÁ½ÌõÏßÖ®ÉÏ, Ö»ÓÐ6´Î(´óÔ¼1/10)µÄ¾ÛÀà×¼È·¶ÈµÍÓÚ.

¶Ô±ÈÍ¼[[f2]](#f2)¿ÉÒÔ¿´³ö, ¶ÔÊýËÆÈ»º¯ÊýºÍ¾ÛÀà×¼È·¶ÈÖ®¼äÓÐ½ÏÇ¿µÄÏà¹ØÐÔ: ¶ÔÕâÈýÀàËã·¨¶øÑÔ, ¾ÛÀà×¼È·¶È¸ßµÄÄ£Äâ´ÎÊý¶ÔÓ¦µÄ¶ÔÊýËÆÈ»º¯ÊýÖµÏàÓ¦½Ï¸ß, ¶ø¾ÛÀà×¼È·¶ÈµÍµÄÄ£Äâ´ÎÊý¶ÔÓ¦µÄ¶ÔÊýËÆÈ»º¯ÊýÖµÒ²Ã÷ÏÔÆ«µÍ. ¾ÍÄÃCEMËã·¨À´Ëµ, µÚ3,13,14,17×éµÄ¾ÛÀà×¼È·¶ÈÆ«µÍ, Ëù¶ÔÓ¦µÄ¶ÔÊýËÆÈ»º¯ÊýÖµÒ²Ã÷ÏÔ±ÈÆäÓà¶þÕßµÍ, ´Ó¶ø´ÓÁíÒ»¸ö½Ç¶ÈÌåÏÖÈýÖÖËã·¨ÔÚµ±Ç°Ä£ÄâÌõ¼þÏÂ²ÎÊý¹À¼ÆÐ§¹ûµÄÓÅÁÓ.

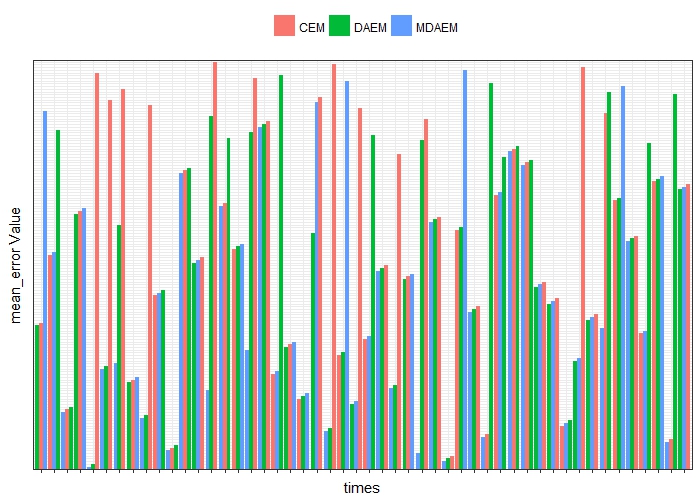


¶ÔÓÚ²ÎÊý¹À¼ÆÐ§¹û, ±¾ÎÄ¸ø³öÁíÒ»¸öÆÀ¼ÛÖ¸±ê, Ä£ÄâËùµÃµÄÈýÖÖËã·¨²ÎÊý¹À¼ÆÖµÓëÑù±¾²ÎÊýÕæÖµµÄ²î¾à:

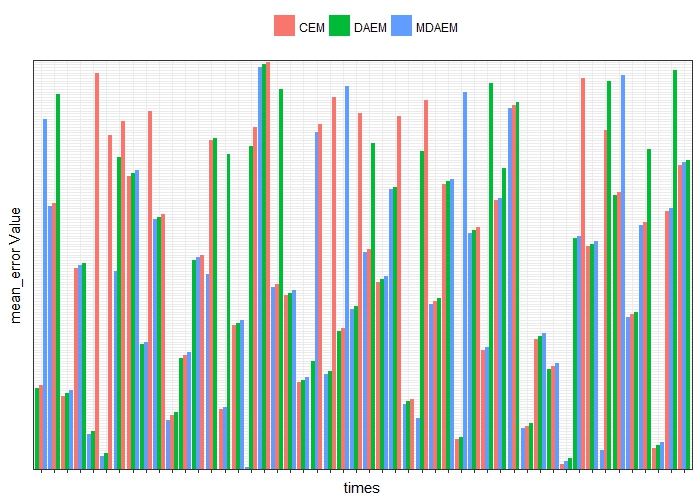
(1)¹ØÓÚ¸ßË¹»ìºÏÄ£ÐÍµÄ±ÈÀý¹À¼Æ. ÈçÍ¼[[f3]](#f3)ËùÊ¾, ÔÚ¶ÔÓ¦»ìºÏ±ÈÀýµÄÈý¸öÏäÏßÍ¼ÉÏ, ÎÒÃÇ¿ÉÒÔÃ÷ÏÔ¿´³öÒì³£ÖµµÄ¸öÊýCEMDA-EMMDA-EM, ÉÏÏÂËÄ·ÖÎ»Ö®²îÒ²ÊÇCEMDA-EMMDA-EM. ÕâÐ©¶¼±íÃ÷ÁËÔÚ»ìºÏ±ÈÀýµÄ¹À¼ÆÐ§¹ûÉÏ, DA-EMËã·¨¹À¼Æ²ÎÊýµÄÎÈ¶¨ÐÔ±ÈCEMËã·¨ºÃ, ¶ø±¾ÎÄÌá³öµÄMDA-EMËã·¨ÓÖÓÅÓÚDA-EMËã·¨.

(2)¹ØÓÚ¸ßË¹»ìºÏÄ£ÐÍµÄ¾ùÖµÏòÁ¿¹À¼Æ, ÈçÍ¼[[f4]](#f4)ËùÊ¾Îª¸÷Ëã·¨¹À¼ÆµÄ¾ùÖµÏòÁ¿ÓëÄ£Äâ¾ùÖµÏòÁ¿ÕæÖµÖ®²îµÄ2·¶Êý, ×ÜÌåÀ´ËµDA-EM Ëã·¨µÄ¾ùÖµÏòÁ¿¹À¼ÆÊÇÒªÓÅÓÚCEM, ¶øMDA-EMËã·¨µÄ¾ùÖµ¹À¼ÆÓÖÊÇÓÅÓÚDA-EMËã·¨µÄ.



(3)¹ØÓÚ¸ßË¹»ìºÏÄ£ÐÍµÄÐ­·½²î¾ØÕó¹À¼Æ, ÈçÍ¼[[f5]](#f5)ËùÊ¾Îª¸÷Ëã·¨¹À¼ÆµÄÐ­·½²î¾ØÕóÓëÄ£ÄâÐ­·½²î¾ØÕóÕæÖµÖ®²îµÄF·¶Êý, ÆäÖÐF·¶ÊýÊÇ°ÑÒ»¸ö¾ØÕóÖÐÃ¿¸öÔªËØµÄÆ½·½ÇóºÍ¿ª¸ùºÅ. Óë¾ùÖµÏòÁ¿ÏàÍ¬, ÎÒÃÇµÃ³ö½áÂÛ: ÈýÖÖËã·¨µÄÐ­·½²î¾ØÕó¹À¼ÆÐ§¹ûÎªMDA-EMDA-EMCEM.



¸ßË¹»ìºÏÄ£ÐÍ·ÂÕæÑÐ¾¿ÖÐËã·¨µÄÊÕÁ²ÐÔºÍ²ÎÊý¹À¼Æ¾«¶È.

|  | CEM | DA-EM | MDA-EM |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- | --- |
| ACCURACY | 0.8482(0.2049) | 0.8609(0.2111) | **0.9085(0.1695)** |  |  |  |  |
| STEP | **258.1(198.1)** | 1117.6(656.1) | 1051.0(2074.5) |  |  |  |  |
| INP | -887.2 | -847.9 | **-837.1** |  |  |  |  |
|  | -907.3 | -867.9 | **-857.1** |  |  |  |  |
|  | -944.3 | -904.9 | **-894.2** |  |  |  |  |
|  | 0.1297 | 0.0728 | **0.0592** |  |  |  |  |
|  | 0.6314 | 0.4788 | **0.3751** |  |  |  |  |
|  | 0.6167 | 0.5935 | **0.4621** |  |  |  |  |

×¢ÊÍ: À¨ºÅÇ°µÄÊý×Ö±íÊ¾50´ÎÄ£ÄâµÄ²ÎÊýÆ½¾ùÖµ, À¨ºÅÖÐµÄÊý×Ö±íÊ¾ÏàÓ¦µÄ·½²î. ¼ÇÎª¸÷Ä£ÐÍ²ÎÊý¹À¼ÆÖµÓë²ÎÊýÕæÖµµÄ¾ù·½Îó²î. ¼Ó´ÖµÄÊý×Ö±íÃ÷Ëù¶ÔÓ¦ÁÐµÄËã·¨¹À¼ÆÐ§¹û×î¼Ñ.

±í[4.1](#tab1)µÄµÚÒ»ÁÐÎªÈýÖÖÄ£ÐÍµÄ¸÷¸öÆÀ¼ÛÖ¸±ê, ÒÀ´ÎÎª: Ä£ÐÍ×¼È·¶È¡¢µü´ú´ÎÊý¡¢¶ÔÊýËÆÈ»º¯ÊýÖµ¡¢AIC¡¢BIC¡¢µÄ¾ù·½Îó²î¡¢µÄ¾ù·½Îó²î¡¢µÄ¾ù·½Îó²î. ÔÚÕâ50´ÎÄ£ÄâÖÐ, ¶ÔÓÚ¸÷¸öÖ¸±êÎÒÃÇÕ¹¿ªÏêÏ¸ÌÖÂÛ:

(1) ¾ÛÀà×¼È·¶È·½Ãæ, MDA-EMËã·¨µÄÆ½¾ù¾ÛÀà×¼È·¶È×î¸ß, DA-EMËã·¨´ÎÖ®, CEMËã·¨Ôò±íÏÖ×î²î.³ý´ËÖ®Íâ, MDA-EMËã·¨ËùµÃ×¼È·¶ÈµÄ±ê×¼²î×îÐ¡, ËùÇóµÄ¹À¼Æ²ÎÊýÒ²×îÎÈ¶¨;

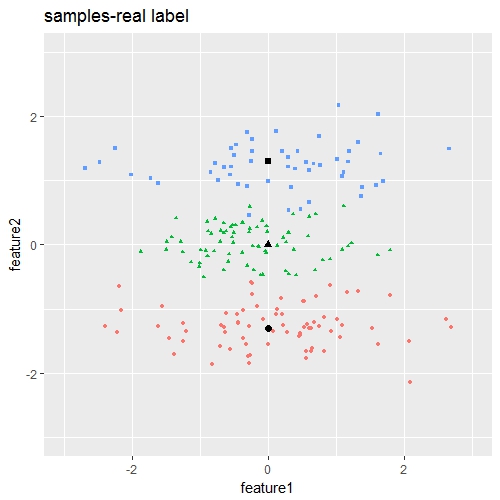
(2) µü´ú´ÎÊý·½Ãæ, CEMËã·¨ºÁÎÞÒÉÎÊÊÇÓÐÓÅÊÆµÄ, ÒòÎª²»¹ÜÊÇDA-EMËã·¨»¹ÊÇMDA-EMËã·¨, ¶¼ÊÇÔÚÄ³¸öÍË»ð²ÎÊýÏÂ½øÐÐµü´úµ½ÊÕÁ², ¶øÃ¿ÓÐÒ»´ÎÍË»ð²ÎÊýµÄ¸üÐÂ¶¼»áÈÃEMËã·¨½øÐÐµü´úµ½ÊÕÁ². ´ÓÄ³ÖÖÒâÒåÉÏËµ, CEMËã·¨ÓëºóÁ½ÕßËã·¨Ö®¼äÊÇÃ»ÓÐ¿É±ÈÐÔµÄ. ÈôÊÇÖ»ÓÐºóÁ½Õß¼ä×÷¶Ô±È, MDA-EMµÄÆ½¾ùµü´ú´ÎÊý¸üÉÙÒ»Ð©. ÓÉÓÚÔÚ¶ÔÊýËÆÈ»º¯ÊýÉÏÒýÈëÁË³Í·£Ïî, ¸ö±ðÇé¿öÏÂµÄµü´ú´ÎÊý²»ÎÈ¶¨, Ê¹µÃµü´ú´ÎÊýµÄ±ê×¼²î±äµÃºÜ´ó. ×ÛºÏÀ´Ëµ, MDA-EMËã·¨ÔÚµü´ú´ÎÊýÉÏÓÅÓÚDA-EMËã·¨.

(3) ¶ÔÊýËÆÈ»º¯ÊýÖµºÍAIC¡¢BICµÈÐÅÏ¢×¼Ôò·½Ãæ, MDA-EMËã·¨¾ßÓÐÃ÷ÏÔµÄÓÅÊÆ.

(4) ²ÎÊýµÄ¾ù·½Îó²î·½Ãæ, MDA-EMËã·¨Ëù¹À¼ÆµÄ²ÎÊýÏà±ÈÆäÓà¶þÕßÒ²ÊÇ¸ü½Ó½üÕæÖµµÄ.

Ä£ÄâÊý¾ÝµÄÕæÊµ¾ÛÀà½á¹û¼ûÍ¼[[f6]](#f6).

Í¼[[f6]](#f6)ÖÐ·½ÐÎµã±íÊ¾µÚ1ÀàÑù±¾Êý¾ÝµÄÕæÊµ±êÇ©, Ô²ÐÎµã±íÊ¾µÚ2ÀàÑù±¾Êý¾ÝµÄÕæÊµ±êÇ©, Èý½ÇÐÎµã±íÊ¾µÚ3ÀàÑù±¾Êý¾ÝµÄÕæÊµ±êÇ©; À¶É«±íÊ¾¾ÛÀàºóµÄµÚ1Àà±êÇ©, ºìÉ«±íÊ¾¾ÛÀàºóµÄµÚ2Àà±êÇ©, ÂÌÉ«±íÊ¾¾ÛÀàºóµÄµÚ3Àà±êÇ©. ¶øºÚÉ«´ó·½ÐÎµã¡¢ºÚÉ«´óÔ²ÐÎµã¡¢ºÚÉ«´óÈý½ÇÐÎµã·Ö±ð±íÊ¾µÚ1,2,3ÀàÑù±¾Êý¾ÝµÄÕæÊµ¾ùÖµÏòÁ¿. Í¼ÖÐXÖá±íÊ¾Ñù±¾Êý¾ÝµÄµÚ1Î¬¶È, YÖá±íÊ¾µÚ2Î¬¶È.



Ëæ»úÑ¡È¡ÈýÖÖÄ£ÐÍ²ÎÊý¹À¼ÆÐ§¹û´æÔÚ²îÒìÐÔµÄÈý×éÄ£ÄâÊµÑé, ²¢¶ÔÆä×öÏêÏ¸·ÖÎö. ÕâÈý×éÄ£ÄâÊµÑé¶ÔÓ¦µÄ¾ÛÀà×¼È·¶È, ¶ÔÊýËÆÈ»º¯ÊýÖµ¼û±í[4.2](#tab2).

Èý×éÄ£ÄâÊµÑé¶ÔÓ¦µÄ¸÷Ö¸±êÖµ.

| ÊµÑé×éºÅ | µÚ14×é | µÚ22×é | µÚ49×é |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- | --- |
| ACCURACY( CEM) | 0.6333 | 0.9900 | 0.5100 |  |  |  |  |
| ACCURACY( DA-EM) | 0.9667 | 0.5667 | 0.3967 |  |  |  |  |
| ACCURACY(MDA-EM) | 0.9767 | 0.9900 | 0.9700 |  |  |  |  |
| Inp( CEM) | -1040.5 | -810.8 | -810.8 |  |  |  |  |
| Inp( DA-EM) | -811.3 | -911.7 | -803.0 |  |  |  |  |
| Inp(MDA-EM) | -990.0 | -878.0 | -826.0 |  |  |  |  |

ÏÂÃæ, ÎÒÃÇ¸ø³öÕâÈý×éÄ£ÄâÊµÑéÖÐÈý×éËã·¨µÄ²ÎÊý¹À¼Æ¶ÔÓ¦µÄ¾ÛÀàÐ§¹û, ²¢·Ö±ð¶ÔÆä×öÏêÏ¸·ÖÎö.

![image](data:application/pdf;base64,)

Í¼[[f7]](#f7), [[f8]](#f8), [[f9]](#f9)Õ¹Ê¾ÁËµÚ14×éÄ£ÄâÊµÑéµÄ¾ÛÀàÐ§¹û. ½áºÏ±í[4.2](#tab2)¿ÉÒÔ¿´³ö, CEMËã·¨ÔÚ¸Ã´ÎÄ£ÄâÊµÑéÖÐÏÝÈëµ½ÁË¾Ö²¿×î´óÖµµã, ²¢ÇÒ¶ÔÊýËÆÈ»º¯ÊýÖµÏà±ÈÁíÍâÁ½ÕßµÍ, Æä¾ÛÀàÐ§¹ûÒ²ºÜÒ»°ã. ¶øMDA-EMËã·¨Ôò¼Ì³ÐÁËDA-EMËã·¨µÄÈ«¾ÖÊÕÁ²ÄÜÁ¦, ²¢ÇÒÔÚ¶ÔÊýËÆÈ»º¯ÊýÖµÉÏÓÐÎ¢ÈõµÄÓÅÊÆ.

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Í¼[[f10]](#f10), [[f11]](#f11), [[f12]](#f12)ÎªµÚ22×éÄ£ÄâÊµÑéµÄ¾ÛÀàÐ§¹û. ÔÚµÚ22´ÎÄ£ÄâÖÐ, CEM´ïµ½ÁËÍêÃÀµÄ¾ÛÀàÐ§¹û, µ«ÊÇÍ¼[[f11]](#f11) È´³öÏÖÁ½¸ö¾ÛÀàÖÐÐÄÖØµþµÄÏÖÏó(ºìÉ«Ñù±¾¾ÛÀàÖÐÐÄºÍÂÌÉ«Ñù±¾¾ÛÀàÖÐÐÄÖØºÏ), µ¼ÖÂ¾ÛÀà×¼È·¶ÈÏÂ½µ. ÓÉ´Ë¿ÉÒÔ¿´³ö, Ê¹ÓÃÍË»ð²ÎÊýÀíÂÛÏÂ½çµÄDA-EMËã·¨ËäÈ»¿ÉÒÔ±ÜÃâËã·¨ÊÕÁ²µ½ÎÈ¶¨µã, µ«ÈÔ²»ÄÜ±ÜÃâ´æÔÚÁ½¸ö»ò¶à¸ö¾ÛÀàÖÐÐÄ¾Û¼¯µÄÏÖÏó. È»¶ø, MDA-EMËã·¨ÔÚµÚ22´ÎÄ£ÄâÖÐÈÔÈ»ÄÜ½ÏºÃµÄ¾ÛÀà, ÆäÔ­ÒòÉÏÎÄÒÑ¾­Ìá¼°²»ÔÙ×¸Êö.

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![image](data:application/pdf;base64,)

Í¼[[f13]](#f13)-[[f14]](#f14)ÒÔ¼°[[f15]](#f15)ÎªµÚ49×éÄ£ÄâÊµÑéµÄ¾ÛÀàÐ§¹û. ÔÚCEMËã·¨ºÍDA-EMËã·¨µÄ¾ÛÀàÐ§¹û¶¼²»ÀíÏëµÄÇéÐÎÏÂ, ±¾ÎÄÌá³öµÄMDA-EMËã·¨ÈÔÄÜ±£³Ö½Ï¸ßµÄ¾ÛÀà×¼È·¶È.

½áºÏ±í[4.1](#tab1)-[4.2](#tab2)µÄÍ³¼ÆÊý¾Ý, ÎÒÃÇ¿ÉÒÔµÃ³ö: ÔÚËæ»ú³õÊ¼²ÎÊýÌõ¼þÏÂ, CEMËã·¨ÈÝÒ×ÊÕÁ²µ½¾Ö²¿×îÓÅ, ËäÈ»DA-EMËã·¨µÄ×ÛºÏÐÔÄÜÓÅÓÚCEMËã·¨. µ«ÓÖÒòÎªÆäÍË»ð²ÎÊýÏÂ½çÀíÂÛµÄ¾ÖÏÞÐÔ¶ø²»ÄÜÍêÈ«±ÜÃâÁ½¸ö»ò¶à¸ö¾ÛÀàÖÐÐÄÖØµþµÄÇé¿ö. ¶ø±¾ÎÄÌá³öµÄMDA-EM Ëã·¨ÔÚ·£º¯ÊýµÄ×÷ÓÃÏÂÄÜÊ¹µÃµü´ú¹ý³ÌÄÜ±Ü¿ª¾ÛÀàÖÐÐÄÖØµþµÄÇé¿ö, Ïà±ÈÓÚDA-EMËã·¨, ´ó·ùÔö¼ÓÁËËã·¨ÊÕÁ²µ½È«¾Ö×îÓÅµÄ¸ÅÂÊ. µ«´Ó±¾ÖÊÉÏ½², MDA-EMËã·¨»¹ÊÇÈ·¶¨ÐÔÍË»ðEMËã·¨, Èô¶ÔÊýËÆÈ»º¯ÊýµÄÁ½¸ö·åµÄ¾àÀë¹ý´óÊ±, ºÍDA-EMËã·¨ÏàÍ¬, MDA-EMËã·¨ÈÔÈ»Ö»ÄÜÊÕÁ²µ½¾Ö²¿×îÓÅ¶ø·ÇÈ«¾Ö×îÓÅ.

ÏÂÃæ, ÎÒÃÇÊ¹ÓÃÓëÉÏÎÄÏàÍ¬µÄÌõ¼þ, Ö»ÁîÑù±¾Êý¾Ý, Çé¿öÏÂ×öÍ¬ÑùµÄ50´ÎÄ£ÄâÊµÑé, µÃµ½±í[4.3](#tab3)ºÍ±í[4.4](#tab4).

ÎÒÃÇ½áºÏ±í[4.1](#tab1)-[4.3](#tab3)ÒÔ¼°[4.4](#tab4)¿ÉÒÔµÃ³ö: µ±Ñù±¾Êý¾Ý½ÏÎª³íÃÜÊ±, ÈýÖÖËã·¨µÄ¹À¼Æ¾«¶È²î¾à²»´ó²¢ÇÒ¶¼±È½Ï¸ß, ÕâÊÇÒòÎªÊ¹ÓÃÔ½¶àµÄÊý¾Ý, »ñµÃµÄÑù±¾ÐÅÏ¢¾ÍÔ½È«Ãæ, ¸ö±ðÀëÈºÑù±¾¶Ô×ÜÌåµÄÓ°ÏìÒ²¾ÍÔ½Ð¡, EMËã·¨Í¬Ê±Ò²Ô½²»ÈÝÒ×ÊÕÁ²µ½¾Ö²¿¼«Öµ; µ±Ñù±¾Êý¾Ý½ÏÎªÏ¡ÊèÊ±, ÈýÖÖËã·¨¹À¼Æ¾«¶ÈµÄ²î¾à½Ï´ó, Í¬Ñù, Ê¹ÓÃÔ½ÉÙµÄÊý¾Ý, »ñµÃµÄÑù±¾ÐÅÏ¢¾ÍÔ½ÉÙ, ÀëÈºÑù±¾¶Ô×ÜÌåµÄÓ°Ïì¾ÍÔ½´ó, EMËã·¨Ò²¾ÍÈÝÒ×ÊÕÁ²µ½¾Ö²¿¼«Öµ. ÖµµÃÒ»ÌáµÄÊÇ, ÔÚÑù±¾¸öÊýºÍµÄÇéÐÎÏÂ, MDA-EMËã·¨´ïµ½ÊÕÁ²µÄµü´ú´ÎÊý´óÔ¼Ö»ÓÐDA-EMËã·¨µÄ, Èý¸öÄ£ÄâÊµÑéÔÚµü´ú´ÎÊý¾ùÖµÉÏ¶¼ÓÅÓÚDA-EMËã·¨. ÔÚDA-EMËã·¨»ù´¡ÉÏ, ¸Ä½øµÄËã·¨ÄÜ¼Ó¿ìµü´úµÄËÙÂÊ.

¸ßË¹»ìºÏÄ£ÐÍ·ÂÕæÑÐ¾¿ÖÐËã·¨µÄÊÕÁ²ÐÔºÍ²ÎÊý¹À¼Æ¾«¶È(n=400).

|  | CEM | DA-EM | MDA-EM |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- | --- |
| ACCURACY | 0.8953(0.1791) | 0.8966(0.1795) | **0.9072(0.1726)** |  |  |  |  |
| STEP | **243.0(166.1)** | 1134.6(781.4) | 585.4(632.4) |  |  |  |  |
| INP | -1127.3 | -1132.2 | **-1102.4** |  |  |  |  |
|  | -1147.3 | -1152.2 | **-1122.4** |  |  |  |  |
|  | -1187.3 | -1192.1 | **-1162.3** |  |  |  |  |
|  | 0.0887 | 0.0679 | **0.0499** |  |  |  |  |
|  | 0.4511 | 0.3818 | **0.3747** |  |  |  |  |
|  | 0.4295 | **0.3795** | 0.4260 |  |  |  |  |

¸ßË¹»ìºÏÄ£ÐÍ·ÂÕæÑÐ¾¿ÖÐËã·¨µÄÊÕÁ²ÐÔºÍ²ÎÊý¹À¼Æ¾«¶È(n=200).

|  | CEM | DA-EM | MDA-EM |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- | --- |
| ACCURACY | 0.75(0.2483) | 0.8154(0.2099) | **0.8764(0.1724)** |  |  |  |  |
| STEP | **258.9(179.9)** | 1246.1(737.9) | 716.0(909.7) |  |  |  |  |
| INP | -607.3 | -613.3 | **-567.3** |  |  |  |  |
|  | -627.3 | -633.3 | **-587.3** |  |  |  |  |
|  | -660.3 | -666.2 | **-620.3** |  |  |  |  |
|  | 0.2031 | 0.1495 | **0.1212** |  |  |  |  |
|  | 0.9575 | 0.7046 | **0.5156** |  |  |  |  |
|  | 0.8562 | 0.7533 | **0.6240** |  |  |  |  |

## ÊµÖ¤·ÖÎö

±¾½ÚÊ¹ÓÃÖøÃûUCI¹«¿ªÊý¾Ý¼¯iris½øÐÐÊµÖ¤·ÖÎö. ÎªÁË·½±ãÍ¼ÏñµÄÏÔÊ¾, ÎÒÃÇÖ»²ÉÓÃ¸ÃÊý¾Ý¼¯µÄµÚ2Î¬¶ÈºÍµÚ4Î¬¶ÈÀ´×öÈýÖÖËã·¨µÄ¾ÛÀà·ÖÎö. Í¬ÑùµØ, ÎÒÃÇÏÈ½¨Á¢¸ßË¹»ìºÏÄ£ÐÍ

ÆäÖÐ, ÎªÈýÀàÑù±¾µÄÕæÊµÐ­·½²î, ÏÖÔÚÁîÎªËæ»ú³éÈ¡µÄÈý¸öÑù±¾µÄÖµ(³õÊ¼¾ÛÀàÖÐÐÄËæ»ú»¯). ÖØ¸´²Ù×÷20´Î, ´Ó¶ø²úÉú20×éÊµÑéÊý¾Ý. ·Ö±ðÊ¹ÓÃÈýÖÖËã·¨¹À¼Æ¸ßË¹»ìºÏÄ£ÐÍµÄ²ÎÊý, ¼ÆËã²ÎÊý¹À¼ÆÖµ¶ÔÓ¦µÄ¾ÛÀà×¼È·¶È¡¢¶ÔÊýËÆÈ»Öµ¡¢¸÷²ÎÊýµÄ¾ù·½Îó²îµÈ, ÒÔ´ËÆÀ¼ÛÈýÖÖËã·¨µÄ¾ÛÀàÐ§¹û¼°²ÎÊý¹À¼ÆµÄÓÐÐ§ÐÔ. ÎÒÃÇÉè¶¨µü´úÊÕÁ²Ìõ¼þÎª.

Í¬Ñù, ÎÒÃÇ¸ø³ö20´ÎËæ»ú³õÊ¼¾ÛÀàÖÐÐÄµÄ¾ÛÀàÐ§¹û±í[4.5](#tab5).

¹ØÓÚirisÊý¾Ý¼¯µÄ²ÎÊý¹À¼ÆÐ§¹û.

|  | CEM | DA-EM | MDA-EM |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- | --- |
| ACCURACY | 0.8422(0.2483) | 0.9272(0.2099) | **0.9467(0.1724)** |  |  |  |  |
| STEP | **99.7(43.3)** | 1731.3(580.8) | 1202.6(815.7) |  |  |  |  |
| INP | -127.3 | -124.2 | **-123.9** |  |  |  |  |
|  | -147.3 | -144.2 | **-143.9** |  |  |  |  |
|  | -177.4 | -174.3 | **-174.0** |  |  |  |  |
|  | 0.3483 | 0.3154 | **0.2297** |  |  |  |  |
|  | 0.4591 | 0.4386 | **0.3121** |  |  |  |  |
|  | **0.0990** | 0.1346 | 0.1129 |  |  |  |  |

´Ó±í[4.5](#tab5)ÖÐ¿ÉÒÔ¿´³ö, ¶ÔÓÚ¸ø¶¨Ëæ»úµÄ³õÊ¼¾ÛÀàÖÐÐÄ, MDA-EMËã·¨×ÜÌå±íÏÖÁ¼ºÃ, ¹À¼ÆÐ§¹û½ÏÎÈ¶¨, µÃµ½µÄ²ÎÊý¹À¼ÆÖµÒ²½ÏÎª×¼È·. µ«ÔÚÉÙÊýÊµÑéÖÐ, MDA-EMËã·¨Í¬ÑùÃ»ÄÜ±ÜÃâÊÕÁ²µ½¾Ö²¿×îÓÅ. µ«¼´Ê¹MDA-EMËãÊÕÁ²µ½¾Ö²¿×îÓÅ, ÆäËùµÃµÄ²ÎÊý¹À¼ÆÐ§¹ûÒ²ÈÔÈ»ºÃÓÚCEMËã·¨ºÍDA-EMËã·¨. Ïà¶Ô¶øÑÔ, CEMËã·¨±íÏÖÆ½Ó¹, ¹À¼ÆÐ§¹û²»Ì«ÎÈ¶¨, µ«ÓÉÓÚÆ½¾ùµü´ú´ÎÊýÔ¶Ô¶ÉÙÓÚÆäÓàÁ½ÖÖËã·¨, Òò´ËÒ²¾ßÓÐÒ»¶¨µÄÊµÓÃÐÔ.

Ëæ»úÌôÑ¡Ò»´Î¾ÛÀàÐ§¹û½Ï²îµÄÊµÑé²¢½«ËüÃÇµÄ¾ÛÀà½á¹ûÓëÕæÊµ¾ÛÀà×ö¶Ô±È, ÈçÍ¼[[f16]](#f16)ËùÊ¾.

![image](data:application/pdf;base64,) ![image](data:application/pdf;base64,)  
![image](data:application/pdf;base64,) ![image](data:application/pdf;base64,)

# ×Ü½áÓëÕ¹Íû

## ×Ü½á

ÓÐÏÞ»ìºÏÄ£ÐÍ×öÎªÒ»ÖÖ½â¾ö¸´ÔÓ·Ö²¼µÄ¹¤¾ß, ¿ÉÒÔ±Æ½ü¼¸ºõËùÓÐµÄ¸ÅÂÊÃÜ¶È, Òò´ËËüÔÚÀíÂÛºÍÓ¦ÓÃÉÏ¾ù±»¹ã·ºÑÐ¾¿. ¶ø×÷Îª×ÔÈ»½ç×î¹ã·º´æÔÚµÄÓÐÏÞ»ìºÏÄ£ÐÍ: ¸ßË¹»ìºÏÄ£ÐÍ. ×÷ÎªÊµ¼Ê²Ù×÷ÖÐ»ù´¡ÓÖÖØÒªµÄ¹¤×÷, ±¾ÎÄÖ÷Òª¶Ô¸ßË¹»ìºÏÄ£ÐÍµÄ²ÎÊý¹À¼ÆÎÊÌâ½øÐÐÑÐ¾¿.

ÓÉÓÚÊý¾ÝÖÐÒþ±äÁ¿µÄ´æÔÚÊ¹µÃEMËã·¨ÊÇ½â¾ö´ËÀàÎÊÌâµÄÊ×ÒªÑ¡Ôñ, µ«ÊÇEMËã·¨´æÔÚÐí¶à¾ÖÏÞÐÔ. Ïà½ÏÓÚ¾­µäEMËã·¨, DA-EMËã·¨ÒýÈëÁËÍË»ð²ÎÊý, ½â¾öÁËÒþ±äÁ¿µÄºóÑé¸ÅÂÊ¹À¼Æ¹ý¶ÈÒÀÀµ²ÎÊý³õÊ¼ÖµµÄÎÊÌâ. È»¶ø,Ê¹ÓÃ¹ýÐ¡µÄÍË»ð²ÎÊý³õÊ¼Öµ½«µ¼ÖÂDA-EMËã·¨ÊÕÁ²µ½ÎÈ¶¨µã¶øÊ¹µü´úÔçÍ£.

±¾ÎÄÔÚYuµÈ(2018)¹ØÓÚÇó½âÍË»ð²ÎÊýÏÂ½çµÄÀíÂÛ»ù´¡ÉÏ, ±¾ÎÄÌá³öÁËÒ»ÖÖ¸Ä½øµÄDA-EMËã·¨. ÔÚ¸ø¶¨Ä£ÐÍ¸öÊýµÄÌõ¼þÏÂ, MDA-EMËã·¨¶Ô²ÎÊý¹À¼ÆµÄ×¼È·ÐÔºÍÎÈ¶¨ÐÔ¸ü¸ß, Ä£ÄâÊµÑéÒ²Ö¤Ã÷ÁËÐÂ·½·¨ÄÜÓÐÐ§±ÜÃâ¶à¸ö¸ßË¹»ìºÏÄ£ÐÍ¾ùÖµÏòÁ¿ÖØµþµÄÇéÐÎ. µ«ÊÇ¸Ã·½·¨µÄÊýÖµÇó½â¹ý³Ì½ÏÎª¸´ÔÓ, ÇÒÆä½¥½øÐÔÓÐ´ýÖ¤Ã÷, ÕâÐ©¶¼ÊÇÖµµÃ½øÒ»²½ÑÐ¾¿µÄÎÊÌâ.

## Î´À´µÄ¹¤×÷

ÏÂÃæÕ¹¿ª¼¸¸öÍØÕ¹ÐÔÎÊÌâ, ¼´ÆäËûµÄÓÐÏÞ»ìºÏÄ£ÐÍ²ÎÊý¹À¼Æ, ²»Í¬³É·ÖµÄ¶àÔª¸ßË¹»ìºÏÄ£ÐÍ¼°Ëã·¨ÓÅ»¯ÎÊÌâ.

### ÆäËûµÄÓÐÏÞ»ìºÏÄ£ÐÍ²ÎÊý¹À¼Æ¼°²»Í¬³É·ÖµÄ»ìºÏÄ£ÐÍ

ÓÉÓÚÎÄÕÂÆª·ùµÄ¾ÖÏÞÐÔ, ±¾ÎÄÖ÷ÒªÑÐ¾¿µÄ»ìºÏÄ£ÐÍÊÇ¸ßË¹»ìºÏÄ£ÐÍ, È»¶ø²´ËÉ»ìºÏÄ£ÐÍ¡¢¶þÏî»ìºÏÄ£ÐÍÒ²ÊÇ·Ç³£¾ßÓÐÑÐ¾¿¼ÛÖµµÄ, µÚÈýÕÂËùÌá³öµÄ¸Ä½øËã·¨µÄË¼ÏëÒÀ¾ÉÊÇ¿ÉÒÔÓ¦ÓÃµ½ÕâÐ©Ä£ÐÍµ±ÖÐµÄ.

´ËÍâ, ±¾ÎÄËùÑÐ¾¿µÄ»ìºÏÄ£ÐÍ¶¼ÊÇÍ¬ÖÊÐÔ»ìºÏÄ£ÐÍ, ¼´ËùÓÐµÄ·ÖÄ£ÐÍ¶¼ÊÇÊôÓÚÒ»Àà(¸ßË¹Ä£ÐÍ)µÄ. ¸üÎªÒ»°ã»¯µÄÎÊÌâ, ÊÇÑÐ¾¿²»Í¬³É·ÖµÄ»ìºÏÄ£ÐÍ, ÖÁÓÚÈçºÎÓ¦ÓÃÊÇÎÒÃÇÎ´À´½«½øÐÐµÄ¹¤×÷.

### Ëã·¨ÓÅ»¯ÎÊÌâ

×îÖµÎÊÌâÒ»Ö±ÊÇ±»¹ã·ºÑÐ¾¿µÄ¾­µäÎÊ´ð. ÎÄÖÐµÚ¶þÕÂÌá³öÁËÒ»ÖÖ¸Ä½øµÄDA-EMËã·¨, ÐÂËã·¨¼Ó¿ìÁËÊÕÁ²ËÙ¶È, Í¬Ê±ÔÚ²ÎÊý¹À¼ÆÉÏ±ÈDA-EM Ëã·¨¸ü¼Ó×¼È·¼°ÎÈ¶¨. È»¶ø, ÓëDA-EMËã·¨ÏàÍ¬, µ±¶ÔÊýËÆÈ»º¯ÊýµÄÁ½¸ö¼«ÖµµãÏà¾à¹ýÔ¶Ê±, ¸ÃËã·¨ÒÀ¾ÉÖ»ÄÜÊÕÁ²µ½¾Ö²¿×î´óÖµ, ¶ø²»ÄÜ±£Ö¤»ñµÃÈ«¾Ö×î´óÖµ. µÚÈýÕÂÍ¨¹ýÐÞ¸ÄDA-EMËã·¨×î´ó³Í·£¶ÔÊýËÆÈ»º¯Êý, ¸ÃËã·¨Ò»·½ÃæÐèÒªÍ¨¹ý½»²æÑéÖ¤½øÐÐµ÷²Î, ÁíÒ»·½ÃæÔÚÃ¿´Îµü´úµÄM²½¶¼ÐèÒªÇó½â·½³Ì×é, ¶øÔÚµü´úµÄ¹ý³ÌÖÐºÜÈÝÒ×³öÏÖ¾ØÕóÆæÒìµÄÇéÐÎ. Ç°Á½Õß¶¼ÒªÏûºÄ´óÁ¿µÄ¼ÆËã³É±¾. Í¬ÑùµÄ, ¸ÃËã·¨ÎÞ·¨±£Ö¤ÊÕÁ²µ½Ä¿±êº¯ÊýµÄÈ«¾Ö×î´óÖµ. Òò´Ë, Ïà¹ØËã·¨µÄÓÅ»¯ÎÊÌâ½«ÊÇÎÒÃÇÎ´À´µÄ¹¤×÷Ö®Ò».

1.2

1

Ê±¼ä¹ýµÃ·É¿ì, ÎÒµÄÑÐ¾¿ÉúÉúÑÄ¼´½«Ó­À´ÁËÎ²Éù. ¸ÐÐ»Õã¹¤ÉÌ¸øÓèÎÒµÄÃÀºÃ»ØÒä, ÔÚÕâÀïÎÒÑ§Ï°ÁËÐí¶à, Ò²³É³¤ÁËÐí¶à, Ò²ÊÜµ½ÁËÐí¶à°ïÖú. ÔÚÂÛÎÄÍê³ÉÖ®¼Ê, ÎÒÏë¶ÔËùÓÐ°ïÖú¹ýÎÒµÄÈËËµÉùÐ»Ð».

Ê×ÏÈ, ÎÒÒª¸ÐÐ»ÎÒµÄµ¼Ê¦ÍõÎ°¸Õ½ÌÊÚ. ÕýÊÇÓÐÁËÍõÀÏÊ¦µÄ°ïÖú, ÎÒµÄÂÛÎÄ²ÅÄÜ¹»Ë³ÀûÍê³É. ÔÚÑ§Ï°ÉÏ, ÍõÀÏÊ¦×ÜÊÇ¶ÔÎÒÄÍÐÄÖ¸µ¼, ÔÚÎÒÓöµ½À§ÄÑÊ±ÄÜ¼°Ê±ÎªÎÒÖ¸µãÃÔ½ò, °ïÖúÎÒ¿Ë·þÑ§Ï°Â·ÉÏµÄÒ»¸ö¸öÄÑ¹Ø. ÍõÀÏÊ¦¶ÔÓÚÑ§ÊõµÄÑÏ½÷ÒÔ¼°¶ÔÉú»îµÄÀÖ¹ÛÌ¬¶È, ÉîÉîÓ°Ïì×ÅÎÒ. ÔÚÉú»îÉÏ, ÍõÀÏÊ¦Ò²¾­³£¹ØÐÄÎÒ, ¸øÎÒÎÞÎ¢²»ÖÁµÄ¹Ø»³, ½ÌÎÒÎªÈË´¦ÊÀµÄµÀÀí.

Æä´Î, ÎÒÒª¸ÐÐ»Ã÷ÈðÐÇÀÏÊ¦ºÍ¶­Ñ©Ã·ÀÏÊ¦. ËûÃÇ²»½ö½ÌÊÚ¸øÎÒ×¨ÒµµÄÀíÂÛÖªÊ¶, »¹¿ªÍØÁËÎÒÔÚ»úÆ÷Ñ§Ï°µÀÂ·ÉÏµÄÊÓÒ°, ÊÇÎÒÄÜ¹»Íê³ÉÕâÆªÂÛÎÄµÄÇ¿´óÖúÁ¦.

´ËÍâÎÒ»¹Òª¸ÐÐ»Ðí¹¢öÎÊ¦ÐÖÔÚÑ§ÒµÉÏ¶ÔÎÒµÄÖî¶àÌáµãºÍ°ïÖú, Í¬Ê±Ò²Ô¤×£Ê¦ÐÖË³Àû²©Ê¿±ÏÒµ.

×îºó, ÎÒÒª¸ÐÐ»ÎÒµÄ¸¸Ä¸, ¸ÐÐ»ÎÒµÄÅ®ÅóÓÑ. ¸ÐÐ»ËûÃÇÒ»Ö±ÒÔÀ´¶ÔÎÒµÄÕÕ¹ËºÍÖ§³Ö, ÈÃÎÒÄÜÃ»ÓÐ¹ËÂÇµØÔÚÇóÑ§Â·ÉÏÒ»Ö±Ç°ÐÐ.

ÔÙ´Î¸ÐÐ»ËùÓÐ°ïÖú¹ýÎÒµÄÈËÃÇ, Ï£ÍûÄãÃÇÄÜ±»Õâ¸öÊÀ½çÎÂÈá¶Ô´ý!

**¶À ´´ ÐÔ Éù Ã÷**

2.0 ±¾ÈËÉùÃ÷Ëù³Ê½»µÄÑ§Î»ÂÛÎÄÊÇ±¾ÈËÔÚµ¼Ê¦Ö¸µ¼ÏÂ½øÐÐµÄÑÐ¾¿¹¤×÷¼°È¡µÃµÄÑÐ¾¿³É¹û¡£¾¡ÎÒËùÖª£¬³ýÁËÎÄÖÐÌØ±ð¼ÓÒÔ±ê×¢ºÍÖÂÐ»µÄµØ·½Íâ£¬ÂÛÎÄÖÐ²»°üº¬ÆäËûÈËÒÑ¾­·¢±í»ò×«Ð´¹ýµÄÑÐ¾¿³É¹û£¬Ò²²»°üº¬±¾ÈËÎª»ñµÃÕã½­¹¤ÉÌ´óÑ§»òÆäËü½ÌÓý»ú¹¹µÄÑ§Î»»òÖ¤Êé¶øÊ¹ÓÃ¹ýµÄ²ÄÁÏ¡£ÓëÎÒÒ»Í¬¹¤×÷µÄÍ¬Ö¾¶Ô±¾ÑÐ¾¿Ëù×öµÄÈÎºÎ¹±Ï×¾ùÒÑÔÚÂÛÎÄÖÐ×÷ÁËÃ÷È·µÄËµÃ÷²¢±íÊ¾Ð»Òâ¡£  
Ñ§Î»ÂÛÎÄ×÷ÕßÇ©Ãû:                   µ¼Ê¦Ç©Ãû:

Ç©×ÖÈÕÆÚ: Äê ÔÂ ÈÕ                                 Ç©×ÖÈÕÆÚ: Äê ÔÂ ÈÕ

**¹ØÓÚÂÛÎÄÊ¹ÓÃÊÚÈ¨µÄËµÃ÷**

      ±¾Ñ§Î»ÂÛÎÄ×÷ÕßÍêÈ«ÁË½âÕã½­¹¤ÉÌ´óÑ§ÓÐ¹Ø±£Áô¡¢Ê¹ÓÃÑ§Î»ÂÛÎÄµÄ¹æ¶¨£ºÕã½­¹¤ÉÌ´óÑ§ÓÐÈ¨±£Áô²¢Ïò¹ú¼ÒÓÐ¹Ø²¿ÃÅ»ò»ú¹¹ËÍ½»ÂÛÎÄµÄ¸´Ó¡¼þºÍ´ÅÅÌ£¬ÔÊÐíÂÛÎÄ±»²éÔÄºÍ½èÔÄ£¬¿ÉÒÔ½«Ñ§Î»ÂÛÎÄµÄÈ«²¿»ò²¿·ÖÄÚÈÝ±àÈëÓÐ¹ØÊý¾Ý¿â½øÐÐ¼ìË÷£¬¿ÉÒÔ²ÉÓÃÓ°Ó¡¡¢ËõÓ¡»òÉ¨ÃèµÈ¸´ÖÆÊÖ¶Î±£´æ¡¢»ã±àÑ§Î»ÂÛÎÄ£¬²¢ÇÒ±¾ÈËµç×ÓÎÄµµµÄÄÚÈÝºÍÖ½ÖÊÂÛÎÄµÄÄÚÈÝÏàÒ»ÖÂ¡£

±£ÃÜµÄÑ§Î»ÂÛÎÄÔÚ½âÃÜºóÒ²×ñÊØ´Ë¹æ¶¨¡£  
Ñ§Î»ÂÛÎÄ×÷ÕßÇ©Ãû:                   µ¼Ê¦Ç©Ãû:

Ç©×ÖÈÕÆÚ: Äê ÔÂ ÈÕ                                 Ç©×ÖÈÕÆÚ: Äê ÔÂ ÈÕ