1. $z = \lambda$, $h(\lambda, R^+, 1) = \{\varnothing\} = q_{\varnothing}$;
2. $z = c$, $h(z, R^+, 1) = \{b\} = q_1$;
3. $z = ca$, $h(z, R^+, 1) = \{b\} = q_1$;
4. $z = cb$, $h(z, R^+, 1) = \{\lambda\} = q_0$;
5. $z = caa$, $h(z, R^+, 1) = \{b\} = q_1$;
6. $z = cab$, $h(z, R^+, 1) = \{\lambda\} = q_0$;
7. $z = caaa$, $h(z, R^+, 1) = \{b\} = q_1$;
8. $z = caab$, $h(z, R^+, 1) = \{\lambda\} = q_0$;
9. $z = caaab$, $h(z, R^+, 1) = \{\lambda\} = q_0$;
10. $z = b$, $h(z, R^+, 1) = \{\varnothing\} = q_{\varnothing}$;
11. $z = bb$, $h(z, R^+, 1) = \{b\} = q_1$;
12. $z = bba$, $h(z, R^+, 1) = \{b\} = q_1$;
13. $z = bbb$, $h(z, R^+, 1) = \{\lambda\} = q_0$;
14. $z = bbaa$, $h(z, R^+, 1) = \{b\} = q_1$;
15. $z = bbab$, $h(z, R^+, 1) = \{\lambda\} = q_0$;
16. $z = bbaab$, $h(z, R^+, 1) = \{\lambda\} = q_0$。

自动机为：

$$A_f(R^+, 1) = (Q, \Sigma, \delta, q_0, F)$$

$Q = \{q_0, q_1, q_{\varnothing}\}$, $\Sigma = \{a, b, c\}$, $F = \{q_0\}$，状态转移示于图 12.34 中的状态图。为了被自动机接受，串必须以 a，b 或 c 开始，并以 b 结尾。同样，带 a，b 或 c 的循环串由 $A_f(R^+, 1)$ 接受。

前述方法的主要优点是实现简单。通过适当的努力，综合过程可以在数字计算机上模拟。主要的缺点是，尽管问题通过上述三条性质简化到一定程度，但还是需要决定恰当的 k 值。

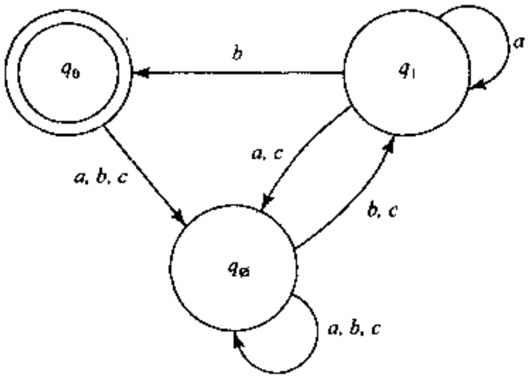


图 12.34 从样本集合 $R^+ = \{caaab, bbaab, caab, bbab, cab, bbb, cb\}$ 推导出来的自动机 $A_f(R^+, 1)$ 的状态图

小结

从第9章开始，对数字图像处理的论述发生了转变，从论述输出图像的过程变为论述输出图像特性的过程，在1.1节中进行了详细解释。本章中的材料本质上是介绍性的，覆盖的题目对于理解对象识别技术的状态很基础。如在本章开头提到的，单个对象的识别是本书结论合乎逻辑的安排。超越这一点，就需要在1.4节中给出的范围以外的概念。特别地，接下来合乎逻辑的步骤将是图像分析方法的研究，这一发展需要机器智能的一些概念。

如在1.1节和1.4中提到的，机器智能及依赖于它的某些领域，比如场景分析和计算机视觉，仍处在它们实践发展的初期阶段。今天，图像分析问题的解决仍是通过具有探索性的方法进行的。当这些方法的确发生了变化时，它们中的大部分恰恰是应用了本书中所涵盖的重要基础技术。

在总结研究了前述12章中的材料后，无论从理论上还是从实践上，读者现在应该可以领略到数字图像处理领域的主要内容了。对于所有的论述请细加琢磨，以便为以后进一步研究本领域或研究以此为基础的相关领域打下坚实的基础。利用许多成像问题特定任务的性质，对基本原理的清晰理解可以显著增加成功解决这些问题的可能性。

参考资料

12.1节到12.2.2节的背景材料来自Duda，Hart和Stork[2001]，还有Tou和Gonzalez[1974]的书籍。由Jain等人[2000]写的综述文章也很重要。Principe等人[1999]所写的书对神经网络进行了很好的描述。电气和电子工程师协会论文集(IEEE Trans.)的特刊“图像处理”[1998]是可以同十年前的一个特刊(IEEE Computer[1988])相媲美的刊物。12.2.3节中提到的材料是介绍性的。实际上，那段论述使用的神经网络模型是多年来提出的大量模型中的一个。然而，我们论述的这个模型是有代表性的，而且是在图像处理过程中使用得相当广泛的模型。识别失真图形的例子改编了Gupta等人[1990，1994]的例子。Gori和Scarselli[1998]写的论文论述了多层次神经网络的分类能力。由Ueda[2000]报告的一个基于使用线性连接的神经网络的方法使分类错误降至最低，这是文中另外一个很好的阅读材料。

12.3.1节中其他附加的阅读材料见Bribiesca和Guzman[1980]的著述。在串匹配方面，见Sze和Yang[1981]，Oommen和Loke[1997]，还有Gdalyahu和Weinshall[1999]的论著。12.3.3节和12.3.4节参考了Gonzalez和Thomason[1978]，Fu[1982]，还有Bunke和Sanfeliu[1990]的著述。也可以参见Tanaka[1995]，Vailaya等人[1998]，Aizaka和Nakamura[1999]，还有Jonk等人[1999]的著述。

习题

12.1 (a)对图12.1中所示模式计算最小距离分类器的判别函数。通过检测(要仔细检测)也许能得到需要的均值向量。

(b)由(a)得到的判别函数绘制决策平面。

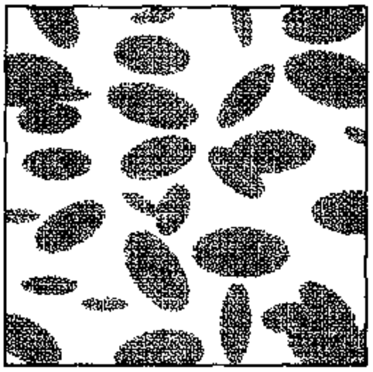
★12.2 说明在模式分类方面,式(12.2.4)和式(12.2.5)具有同样的功能。

12.3 说明由式(12.2.6)给出的平面是 n 维点 $\mathbf{m}_i$ 和 $\mathbf{m}_j$ 间连线的垂直等分线。

★12.4 联系图 12.7 的讨论,说明最小距离分类器如何使用 W 电阻排(W 是类别数)、对每排电阻进行的相加连接(将电流加起来)和一个能选择 W 最大值的最大值选择器来实现。

12.5 说明式(12.2.8)的相关系数具有$[-1,1]$范围内的值。
提示:用矢量形式表示 $\gamma(x,y)$。

★12.6 一个实验产生带有斑点的二值图像,这些小斑点外形近似椭圆(见下图)。斑点有 3 种尺寸,椭圆的主轴平均值为(1.3,0.7),(1.0,0.5),(0.75,0.25)。这些轴的尺寸相对于它们的平均值有 ± 10% 的变化。开发一种图像处理系统,它能够拒绝不完整的或相互重叠的椭圆并依据给出的 3 种尺寸对剩下的单个椭圆进行分类。以方框图的形式显示结果,对于每个部分的操作给出详尽的细节。使用最小距离分类器解决分类问题,清楚地指出如何得到训练样本和如何使用这些样本训练分类器。



12.7 下列模式类具有高斯概率密度函数 $\omega_1:\{(0,0)^T,(2,0)^T,(2,2)^T,(0,2)^T\}$和 $\omega_2:\{(4,4)^T,(6,4)^T,(6,6)^T,(4,6)^T\}$。

(a)假设 $P(\omega_1)=P(\omega_2)=\frac{1}{2}$,求两个类之间的贝叶斯决策边界方程式。

(b)画出边界线。

★12.8 重复习题 12.7,但使用下列模式类:$\omega_1:\{(-1,0)^T,(0,-1)^T,(1,0)^T,(0,1)^T\}$和 $\omega_2:\{(-2,0)^T,(0,-2)^T,(2,0)^T,(0,2)^T\}$。显然这些类不是线性可分的。

12.9 重复习题 12.6,但使用贝叶斯分类器(假设有高斯密度)。清楚地指出如何得到训练样本和如何使用这些样本训练分类器。

★12.10 贝叶斯判别函数 $d_j(\mathbf{x})=p(\mathbf{x}/\omega_j)P(\omega_j),j=1,2,\cdots,W$,用 0-1 失效函数推导。证明这些决策函数最小化了出错概率[提示:出错概率 $p(e)$是 $1-p(c)$,这里 $p(c)$是正确分类的概率]。对于一个属于类 ω_i 的模式向量 $\mathbf{x}$,$p(c/\mathbf{x})=p(\omega_i/\mathbf{x})$。找出 $p(c)$并说明当 $p(\mathbf{x}/\omega_i)P(\omega_i)$是最大值时,$p(c)$取最大值[$p(e)$为最小值]。

12.11 (a)对下列模式类使用感知器算法:$\omega_1:\{(0,0,0)^T,(1,0,0)^T,(1,0,1)^T,(1,1,0)^T\}$和 $\omega_2:\{(0,0,1)^T,(0,1,1)^T,(0,1,0)^T,(1,1,1)^T\}$。令 $c=1$ 和 $\mathbf{w}(1)=$

$(-1,-2,-2,0)^T$。

(**b**)画出(a)中得到的决策平面。说明模式类并指出决策面正的一侧。

★12.12 式(12.2.34)到式(12.2.36)给出的感知器算法可以通过用 −1 乘以模式类 ω_2 以表达得更为简练。此时,算法的正确步骤变为:如果 $\mathbf{w}^T(k)\mathbf{y}(k)>0$,则 $\mathbf{w}(k+1)=\mathbf{w}(k)$,否则 $\mathbf{w}(k+1)=\mathbf{w}(k)+c\mathbf{y}(k)$。这是几个由普通梯度下降公式(见下式)导出的感知器算法公式之一。

$$\mathbf{w}(k+1)=\mathbf{w}(k)-c\left[\frac{\partial J(\mathbf{w},\mathbf{y})}{\partial \mathbf{w}}\right]_{\mathbf{w}=\mathbf{w}(k)}$$

这里 $c>0$,$J(\mathbf{w},\mathbf{y})$ 是准则函数,偏导数为 $\mathbf{w}=\mathbf{w}(k)$ 处的值。说明通过使用准则函数 $J(\mathbf{w},\mathbf{y})=\frac{1}{2}(|\mathbf{w}^T\mathbf{y}|-\mathbf{w}^T\mathbf{y})$,感知器算法公式可以在普通梯度降低过程中得到。这里 $|\arg|$ 是变元的绝对值(注意:关于 $\mathbf{w}$ 的 $\mathbf{w}^T\mathbf{y}$ 偏导数等于 $\mathbf{y}$)。

12.13 证明如果训练模式集合是线性可分离的,在式(12.2.34)到式(12.2.36)中给出的感知器训练算法收敛于有限步[提示:将模式类 ω_2 乘以 −1,并考虑非负门限 T,使感知器训练算法($c=1$)表示为:如果 $\mathbf{w}^T(k)\mathbf{y}(k)>T$,则 $\mathbf{w}(k+1)=\mathbf{w}(k)$,否则 $\mathbf{w}(k+1)=\mathbf{w}(k)+\mathbf{y}(k)$。也许要利用柯西-施瓦茨不等式:$\|\mathbf{a}\|^2\|\mathbf{b}\|^2\geqslant(\mathbf{a}^T\mathbf{b})^2$]。

★12.14 详细说明神经网络的结构和权值可以完全实现与 n 维空间中对两个模式类分类的最小距离分类器相同的功能。

12.15 详细说明神经网络的结构和权值可以完全实现与 n 维空间中对两个模式类分类的贝叶斯分类器相同的功能。这些类都是高斯的并有不同的均值,但其协方差矩阵是相等的。

★12.16 (**a**)在什么条件下,习题 12.14 和习题 12.15 中的神经网络一样?

(**b**)如果用足够数量的样本进行训练,12.2.3 节中开发的多层前馈神经网络产生的德尔塔规则会生成(a)中提到的特殊神经网络吗?

12.17 在两个维度上的两个模式类以下列形式分布:模式类 ω_1 随机地沿着一个半径为 r_1 的圆分布,同样,模式类 ω_2 随机地沿着半径为 r_2 的圆分布,这里 $r_2=2r_1$。用最少的层次和节点指定一个神经网络的结构,对这两个类的模式进行适当分类。

★12.18 重复习题 12.6,但使用神经网络。清楚地指出如何得到训练样本和如何使用这些样本训练分类器。以你的观点选择能解决问题的可能的最简单神经网络。

12.19 说明式(12.2.71)给出的表达式 $h'_j(I_j)=O_j(1-O_j)$[这里 $h'_j(I_j)=\partial h_j(I_j)/\partial I_j$],根据式(12.2.50)($\theta_o=1$)得出。

★12.20 说明式(12.3.2)中的距离度量 $D(A,B)$ 满足式(12.3.3)的性质。

12.21 说明当且仅当 a 和 b 是同样的串时,式(12.3.4)中的 $\beta=\max(|a|,|b|)-\alpha$ 为 0。

12.22 ★(**a**)详细说明一个能够识别形如 ab^na 的模式串的有限自动机。

(**b**)由(a)中的解得到对应的正则文法(不通过检测解决)。

12.23 在两个空间方向上,对 0 和 1 交错组成(类似棋盘模式)的图像给出一个开销大的树文法。假设左上边的元素是 1,并且所有图像结束于左下边的元素 1。

★12.24 使用式(12.3.12)到式(12.3.15)规定的学习过程,去学习一个能识别形如 ab^na 的

串的有限自动机,其中 $n>0$。从样本集合{*aba*, *abba*, *abbba*}开始。如果这个集合对于使用算法找到字符 *b* 重复出现的规律是不充足的,则增加样本串,直到算法可以找到其中的规律。

12.25 说明与图 12.30 有关的树自动机可以接受图 12.31(b)中给出的树。

12.26 某一工厂为运动会生产了大量的小美国国旗。质量控制小组发现,在生产高峰期,某些印刷机器有少印(随机地)一到三个星或一到两条整条条纹的倾向。除了这些错误以外,旗子的其他方面都很好。尽管对于全部产品来说,含有错误的旗子只占很少比率,工厂经理仍决定解决这一问题。在大量的调查之后,他总结出应用图像处理技术自动检测是解决问题最经济的方法。具体说明如下:旗子尺寸约为 12.5 cm × 7.5 cm。他们将生产线(独立的,但定位上有 15%的偏差)纵向移动的速度减少到大约 50 cm/s,旗子之间有大约 5 cm 的间隙。这里"大约"指 ±5%。工厂经理让你为每条生产线设计一个图像处理系统。在决定所采用方法的可用性时,简单性和花费是重要参量。基于图 1.23 设计一个完善的系统。将你的解决方案简要(但要清楚)写成文档(包括各种假设和说明)向工厂经理汇报。

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