of change of pairs we have:

$$\begin{aligned}\frac{d[XY](\underline{d})}{dt} &= \tau[XX](\underline{d})\frac{\int K(\underline{r})[XY](\underline{r})[XY](\underline{r}-\underline{d})d\underline{r}}{X^2Y}, \\ &\quad - \tau[XY](\underline{d})\frac{\int K(\underline{r})[XY](\underline{r})[YY](\underline{r}-\underline{d})d\underline{r}}{XY^2}, \\ &\quad - \tau[XY](\underline{d})K(\underline{d}) + \gamma[YY](\underline{d}) - \gamma[XY](\underline{d}).\end{aligned} \tag{7.23}$$

Here the first term corresponds to the infection of one susceptible (of a XX pair separated by a distance $\underline{d}$) by an infectious individual who is distance $\underline{r}$ from the target susceptible and therefore distance $\underline{r}-\underline{d}$ from the other susceptible within the pair. This term is composed of three pair-wise components, because all three individuals involved in the event have associated correlations—this differs from the network approach where all triples are "linear"; here all triples form triangles. The second term refers to the loss of an XY pair due to the susceptible being infected from outside the pair. The other three terms do not involve any external interactions and are: infection within an XY pair, recovery within a YY pair, and recovery within an XY pair.

Pair-wise models for spatial processes provide a deterministic approximation for individual-based spatial models.

Although the solution of complex integro-differential equations such as equation (7.23) is an involved process, for some spatial kernels semi-analytic results are possible (Bolker and Pacala 1997; Bolker 1999; Dieckmann et al. 2000) and hence a more comprehensive and robust understanding of the general effects of spatial interaction are possible.

7.9. FUTURE DIRECTIONS

It has only been over the past decade that spatial models have been used in epidemiological applications, and in many areas the implications of spatial structure have yet to be understood. Two main problems stand out as being of both theoretical and applied importance.

The first is the theoretical question of scale—which has applied implications in terms of what is computationally feasible. It is clear from the work in this chapter that spatial structure occurs and operates at a variety of scales; however, it is not clear whether it is necessary to simulate all of these scales to derive accurate predictions of the epidemiological dynamics. In particular, is it always necessary to model the underlying network structure of social contacts to create reliable epidemic models at the national (or international) level? This is one aspect of a more general issue: When can complex fine-scale heterogeneities be absorbed into parameterization and when must they be modeled explicitly? The approximation methods outlined above may be able to provide some insights and lead to general rules about when spatial structure is important.

Second, many difficulties still exist with parameterizing spatial models, either from epidemiological or behavioral data. This is exemplified by three different problems. First, we have very little information about the network of social contacts through which most airborne infections spread, although this has recently become an area of intense focus. Understanding the role of transmission network structure is fundamental to all infectious

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