A NonLocal Epidemic Model with Age Structure, Space Dependence and Quarantine

R.M. Colombo, M. Garavello, F. Marcellini, E. Rossi

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ECMI, 29.04.2020

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A NonLocal Epidemic Model

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(Kermack, McKendrick: Proc. Royal Soc. A, 1927)

Susceptible	Infected	Recovered
$S = S(t)$	$I = I(t)$	$R = R(t)$

$$\left\{\begin{array}{rcl} \dot S & = & \text{mortality} + \text{interaction} \\ \dot I & = & \text{mortality} + \text{interaction} \\ \dot R & = & \text{mortality} + \text{interaction} \end{array}\right.$$

A NonLocal Epidemic Model

(Kermack, McKendrick: Proc. Royal Soc. A, 1927)

With Quarantine

Susceptible		Infected		Recovered
$S = S(t)$		$I = I(t)$		$R = R(t)$
		↙ ↘		
Susceptible	Infective		Hospitalized	Recovered
$S = S(t)$	$I = I(t)$		$H = H(t)$	$R = R(t)$

$$\left\{\begin{array}{rcl} \dot S & = & \text{mortality} + \text{interaction} \\ \dot I & = & \text{mortality} + \text{interaction} \\ \dot H & = & \text{mortality} + \text{interaction} \\ \dot R & = & \text{mortality} + \text{interaction} \end{array}\right.$$

A NonLocal Epidemic Model – $a \in \mathbb{R}_+$

(Kermack, McKendrick: Proc. Royal Soc. A, 1927)

With Quarantine, Age Structure

Susceptible		Infected		Recovered
$S = S(t)$		$I = I(t)$		$R = R(t)$
		↙ ↘		
Susceptible	Infective		Hospitalized	Recovered
$S = S(t, a)$	$I = I(t, a)$		$H = H(t, a)$	$R = R(t, a)$

$$\left\{\begin{array}{rcl} \partial_t S + \partial_a S & = & \text{mortality} + \text{interaction} \\ \partial_t I + \partial_a I & = & \text{mortality} + \text{interaction} \\ \partial_t H + \partial_a H & = & \text{mortality} + \text{interaction} \\ \partial_t R + \partial_a R & = & \text{mortality} + \text{interaction} \end{array}\right.$$

A NonLocal Epidemic Model – $a \in \mathbb{R}_+$, $x \in X$

(Kermack, McKendrick: Proc. Royal Soc. A, 1927)

With Quarantine, Age Structure and Space Dependence

Susceptible		Infected		Recovered
$S = S(t)$		$I = I(t)$		$R = R(t)$
Susceptible	Infective	↙ ↘	Hospitalized	Recovered
$S = S(t,a,x)$	$I = I(t,a,x)$		$H = H(t,a,x)$	$R = R(t,a,x)$
$v_S = v_S(t,a,x)$	$v_I = v_I(t,a,x)$			$v_R = v_R(t,a,x)$

$$\left\{\begin{array}{lcl}
\partial_t S + \partial_a S + \mathrm{div}_x (v_S\, S) & = & \text{mortality} + \text{interaction}\\
\partial_t I + \partial_a I + \mathrm{div}_x (v_I\, I) & = & \text{mortality} + \text{interaction}\\
\partial_t H + \partial_a H & = & \text{mortality} + \text{interaction}\\
\partial_t R + \partial_a R + \mathrm{div}_x (v_R\, R) & = & \text{mortality} + \text{interaction}
\end{array}\right.$$

A NonLocal Epidemic Model – $a \in \mathbb{R}_+$, $x \in X$

(Colombo, Garavello, Marcellini, Rossi: In preparation, 2020)

With Quarantine, Age Structure and Space Dependence

Susceptible		Infected		Recovered
$S = S(t)$		$I = I(t)$		$R = R(t)$

Susceptible	Infective	Hospitalized	Recovered
$S = S(t,a,x)$	$I = I(t,a,x)$	$H = H(t,a,x)$	$R = R(t,a,x)$
$v_S = v_S(t,a,x)$	$v_I = v_I(t,a,x)$		$v_R = v_R(t,a,x)$

$$\left\{\begin{array}{rcl}
\partial_t S + \partial_a S + \operatorname{div}_x (v_S\, S) & = & \text{mortality} + \text{interaction} \\
\partial_t I + \partial_a I + \operatorname{div}_x (v_I\, I) & = & \text{mortality} + \text{interaction} \\
\partial_t H + \partial_a H & = & \text{mortality} + \text{interaction} \\
\partial_t R + \partial_a R + \operatorname{div}_x (v_R\, R) & = & \text{mortality} + \text{interaction}
\end{array}\right.$$

A NonLocal Epidemic Model – Mortality

$$\left\{\begin{array}{rcl} \partial_t S + \partial_a S + \mathrm{div}_x\left(v_S\, S\right) & = & \text{mortality} + \text{interaction} \\ \partial_t I + \partial_a I + \mathrm{div}_x\left(v_I\, I\right) & = & \text{mortality} + \text{interaction} \\ \partial_t H + \partial_a H & = & \text{mortality} + \text{interaction} \\ \partial_t R + \partial_a R + \mathrm{div}_x\left(v_R\, R\right) & = & \text{mortality} + \text{interaction} \end{array}\right.$$

A NonLocal Epidemic Model – Mortality

Proportional to the population,
with a coefficient time, age and space dependent

$$\left\{\begin{array}{rcl}
\partial_t S + \partial_a S + \mathrm{div}_x\,(v_S\, S\,) + \mu_S\, S & = & \text{interaction} \\
\partial_t I \;+\; \partial_a I \;+\; \mathrm{div}_x\,(v_I\, I) + \mu_I\; I & = & \text{interaction} \\
\partial_t H + \partial_a H + \mu_H\, H & = & \text{interaction} \\
\partial_t R + \partial_a R + \mathrm{div}_x\,(v_R\, R) + \mu_R\, R & = & \text{interaction}
\end{array}\right.$$

$$\mu_S = \mu_S(t,a,x), \quad \mu_I = \mu_I(t,a,x)$$
$$\mu_H = \mu_H(t,a,x), \quad \mu_R = \mu_R(t,a,x)$$

A NonLocal Epidemic Model – Interactions

$$\left\{\begin{array}{r} \partial_t S + \partial_a S + \mathrm{div}_x\,(v_S\, S\,) + \mu_S\, S \;= \text{interaction} \\ \partial_t I \;+\; \partial_a I \;+\; \mathrm{div}_x\,(v_I\, I) + \mu_I\;\, I \;\;= \text{interaction} \\ \partial_t H + \partial_a H + \mu_H\, H = \text{interaction} \\ \partial_t R + \partial_a R + \mathrm{div}_x\,(v_R\, R) + \mu_R\, R = \text{interaction} \end{array}\right.$$

A NonLocal Epidemic Model – Interactions

$$
\left\{
\begin{array}{r@{}l}
\partial_t S + \partial_a S + \operatorname{div}_x (v_S\, S) + \mu_S\, S & = -(S \to I) \\
\partial_t I + \partial_a I + \operatorname{div}_x (v_I\, I) + \mu_I\, I & = -(I \to H) - (I \to R) + (S \to I) \\
\partial_t H + \partial_a H + \mu_H\, H & = \quad (I \to H) - (H \to R) \\
\partial_t R + \partial_a R + \operatorname{div}_x (v_R\, R) + \mu_R\, R & = \quad (I \to R) + (H \to R)
\end{array}
\right.
$$

A NonLocal Epidemic Model – Interactions

$$\left\{\begin{array}{rl} \partial_t S + \partial_a S + \operatorname{div}_x (v_S\, S) + \mu_S\, S & = -(S \to I) \\ \partial_t I + \partial_a I + \operatorname{div}_x (v_I\, I) + \mu_I\, I & = -\kappa\, I - (I \to R) + (S \to I) \\ \partial_t H + \partial_a H + \mu_H\, H & = \kappa\, I - (H \to R) \\ \partial_t R + \partial_a R + \operatorname{div}_x (v_R\, R) + \mu_R\, R & = (I \to R) + (H \to R) \end{array}\right.$$

$$\kappa = \kappa(t, a, x)$$

$(I \to H) = \kappa\, I$ rate at which infective individuals are confined

A NonLocal Epidemic Model – Interactions

$$\left\{\begin{array}{r}
\partial_t S + \partial_a S + \mathrm{div}_x\left(v_S\, S\right) + \mu_S\, S = -(S \to I) \\
\partial_t I + \partial_a I + \mathrm{div}_x\left(v_I\, I\right) + \mu_I\, I = -\kappa\, I - \vartheta\, I + (S \to I) \\
\partial_t H + \partial_a H + \mu_H\, H = \kappa\, I - (H \to R) \\
\partial_t R + \partial_a R + \mathrm{div}_x\left(v_R\, R\right) + \mu_R\, R = \vartheta\, I + (H \to R)
\end{array}\right.$$

$$\kappa = \kappa(t, a, x), \qquad \vartheta = \vartheta(t, a, x)$$

$(I \to H) = \kappa\, I$ rate at which infective individuals are confined

$(I \to R) = \vartheta\, I$ rate at which infective individuals recover

A NonLocal Epidemic Model – Interactions

$$\begin{cases} \partial_t S + \partial_a S + \mathrm{div}_x (v_S\, S) + \mu_S\, S = -(S \to I) \\ \partial_t I + \partial_a I + \mathrm{div}_x (v_I\, I) + \mu_I\, I = -\kappa\, I - \vartheta\, I + (S \to I) \\ \partial_t H + \partial_a H + \mu_H\, H = \kappa\, I - \eta\, H \\ \partial_t R + \partial_a R + \mathrm{div}_x (v_R\, R) + \mu_R\, R = \vartheta\, I + \eta\, H \end{cases}$$

$$\kappa = \kappa(t,a,x), \quad \vartheta = \vartheta(t,a,x), \quad \eta = \eta(t,a,x)$$

$(I \to H) = \kappa\, I$ rate at which infective individuals are confined

$(I \to R) = \vartheta\, I$ rate at which infective individuals recover

$(H \to R) = \eta\, H$ rate at which hospitalized individuals recover

A NonLocal Epidemic Model – Interactions

$$\begin{cases} \partial_t S + \partial_a S + \mathrm{div}_x (v_S\, S) + \mu_S\, S = -(S \to I) \\ \partial_t I + \partial_a I + \mathrm{div}_x (v_I\, I) + \mu_I\, I = -\kappa\, I - \vartheta\, I + (S \to I) \\ \partial_t H + \partial_a H + \mu_H\, H = \kappa\, I - \vartheta\, H \\ \partial_t R + \partial_a R + \mathrm{div}_x (v_R\, R) + \mu_R\, R = \vartheta\, I + \vartheta\, H \end{cases}$$

$$\kappa = \kappa(t, a, x), \quad \vartheta = \vartheta(t, a, x), \quad \eta = \eta(t, a, x)$$

$(I \to H) = \kappa\, I$ rate at which infective individuals are confined

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$(H \to R) = \eta\, H$ rate at which hospitalized individuals recover

$(S \to I)$ rate at which susceptible individuals are infected

A NonLocal Epidemic Model – Interactions

$$\begin{cases} \partial_t S + \partial_a S + \operatorname{div}_x (v_S\, S) + \mu_S\, S = -(S \to I) \\ \partial_t I + \partial_a I + \operatorname{div}_x (v_I\, I) + \mu_I\, I = -\kappa\, I - \vartheta\, I + (S \to I) \\ \partial_t H + \partial_a H + \mu_H\, H = \kappa\, I - \vartheta\, H \\ \partial_t R + \partial_a R + \operatorname{div}_x (v_R\, R) + \mu_R\, R = \vartheta\, I + \vartheta\, H \end{cases}$$

$$\kappa = \kappa(t,a,x), \qquad \vartheta = \vartheta(t,a,x), \qquad \eta = \eta(t,a,x)$$

$(I \to H) = \kappa\, I$ rate at which infective individuals are confined

$(I \to R) = \vartheta\, I$ rate at which infective individuals recover

$(H \to R) = \eta\, H$ rate at which hospitalized individuals recover

$(S \to I)$ rate at which susceptible individuals are infected

$$(S \to I) = \int_{\mathbb{R}_+} \int_X \rho(t,a,\alpha,x,\xi)\, I(t,\alpha,\xi)\, \mathrm{d}\xi\, \mathrm{d}\alpha\; S(t,a,x)$$

A NonLocal Epidemic Model – Interactions

$$
\begin{cases}
\partial_t S + \partial_a S + \mathrm{div}_x (v_S\, S) + \mu_S\, S = -(S \to I) \\
\partial_t I + \partial_a I + \mathrm{div}_x (v_I\, I) + \mu_I\, I = -\kappa\, I - \vartheta\, I + (S \to I) \\
\partial_t H + \partial_a H + \mu_H\, H = \kappa\, I - \vartheta\, H \\
\partial_t R + \partial_a R + \mathrm{div}_x (v_R\, R) + \mu_R\, R = \vartheta\, I + \vartheta\, H
\end{cases}
$$

$$
\kappa = \kappa(t,a,x), \quad \vartheta = \vartheta(t,a,x), \quad \eta = \eta(t,a,x)
$$

$(I \to H) = \kappa\, I$ rate at which infective individuals are confined

$(I \to R) = \vartheta\, I$ rate at which infective individuals recover

$(H \to R) = \eta\, H$ rate at which hospitalized individuals recover

$(S \to I)$ rate at which susceptible individuals are infected

$$
(S \to I) = \int_{\mathbb{R}_+} \int_X \rho(t,a,\alpha,x,\xi)\, I(t,\alpha,\xi)\, \mathrm{d}\xi\, \mathrm{d}\alpha\; S(t,a,x)
$$

(Colombo, Garavello, Marcellini, Rossi: In preparation, 2020)

A NonLocal Epidemic Model – Interactions

$$\left\{\begin{array}{l} \partial_t S + \partial_a S + \mathrm{div}_x\left(v_S\, S\right) + \mu_S\, S = -(S \to I) \\ \partial_t I + \partial_a I + \mathrm{div}_x\left(v_I\, I\right) + \mu_I\, I = -\kappa\, I - \vartheta\, I + (S \to I) \\ \partial_t H + \partial_a H + \mu_H\, H = \kappa\, I - \vartheta\, H \\ \partial_t R + \partial_a R + \mathrm{div}_x\left(v_R\, R\right) + \mu_R\, R = \vartheta\, I + \vartheta\, H \end{array}\right.$$

$$\kappa = \kappa(t,a,x), \quad \vartheta = \vartheta(t,a,x), \quad \eta = \eta(t,a,x)$$

$(I \to H) = \kappa\, I$ rate at which infective individuals are confined

$(I \to R) = \vartheta\, I$ rate at which infective individuals recover

$(H \to R) = \eta\, H$ rate at which hospitalized individuals recover

$(S \to I)$ rate at which susceptible individuals are infected

$$(S \to I) = \int_{\mathbb{R}_+} \int_X \rho(t,a,\alpha,x,\xi)\, I(t,\alpha,\xi)\, d\xi\, d\alpha\;\; S(t,a,x)$$

(Hopefully, no $(R \to S)$ term!)

A NonLocal Epidemic Model – Role of ρ

$$\begin{cases} \partial_t S + \partial_a S + \operatorname{div}_x (v_S\, S) + \mu_S\, S & = & -\iint \rho\, I \,\mathrm{d}\alpha\ \mathrm{d}\xi\ S \\ \partial_t I + \partial_a I + \operatorname{div}_x (v_I\, I) + \mu_I\, I & = & \iint \rho\, I \,\mathrm{d}\alpha\ \mathrm{d}\xi\ S - \kappa\, I - \vartheta\, I \\ \partial_t H + \partial_a H + \mu_H\, H & = & \kappa\, I - \eta\, H \\ \partial_t R + \partial_a R + \operatorname{div}_x (v_R\, R) + \mu_R\, R & = & \vartheta\, I + \eta\, H \end{cases}$$

$$(S \to I) = \int_{\mathbb{R}_+} \int_X \rho(t, a, \alpha, x, \xi)\, I(t, \alpha, \xi)\, \mathrm{d}\xi\ \mathrm{d}\alpha\ \ S(t, a, x)$$

ρ describes the disease transmission

e.g.: $\|x - \xi\| > \delta \ \Rightarrow\ \rho = 0$

A NonLocal Epidemic Model – Role of ρ and κ

$$\begin{cases} \partial_t S + \partial_a S + \mathrm{div}_x (v_S\, S) + \mu_S\, S &= -\iint \rho\, I\, \mathrm{d}\alpha\, \mathrm{d}\xi\; S \\ \partial_t I + \partial_a I + \mathrm{div}_x (v_I\, I) + \mu_I\, I &= \iint \rho\, I\, \mathrm{d}\alpha\, \mathrm{d}\xi\; S - \kappa\, I - \vartheta\, I \\ \partial_t H + \partial_a H + \mu_H\, H &= \kappa\, I - \eta\, H \\ \partial_t R + \partial_a R + \mathrm{div}_x (v_R\, R) + \mu_R\, R &= \vartheta\, I + \eta\, H \end{cases}$$

$$(S \to I) = \int_{\mathbb{R}_+} \int_X \rho(t,a,\alpha,x,\xi)\, I(t,\alpha,\xi)\, \mathrm{d}\xi\, \mathrm{d}\alpha\;\; S(t,a,x)$$

ρ describes the disease transmission

κ describes the isolation of infective individuals

A NonLocal Epidemic Model – Computing R_o

Nondimensional, time dependent, independent of a and x:

$$R_o(t) = \frac{\text{(average infection rate} \times \text{number of susceptibles)}}{\text{(average recovery rate)}}$$

A NonLocal Epidemic Model – Computing R_o

Nondimensional, time dependent, independent of a and x:

$$R_o(t) = \frac{\text{(average infection rate} \times \text{number of susceptibles)}}{\text{(average recovery rate)}}$$

$$\boxed{\boxed{R_o(t) = \frac{\dfrac{\int \rho\, I\, S}{\int I}}{\dfrac{\int \vartheta\, I + \int \eta\, H}{\int I + \int H}}}}$$

A NonLocal Epidemic Model – Computing R_o

Nondimensional, time dependent, independent of a and x:

$$R_o(t) = \frac{\text{(average infection rate} \times \text{number of susceptibles)}}{\text{(average recovery rate)}}$$

$$R_o(t) = \dfrac{\dfrac{\iiiint \rho(t,a,\alpha,x,\xi)\, I(t,\alpha,\xi)\, S(t,a,x)\, \mathrm{d}\xi\, \mathrm{d}\alpha\, \mathrm{d}x\, \mathrm{d}a}{\iint I(t,a,x)\, \mathrm{d}x\, \mathrm{d}a}}{\dfrac{\iint \vartheta(t,a,x)\, I(t,a,x)\, \mathrm{d}x\, \mathrm{d}a + \iint \eta(t,a,x)\, H(t,a,x)\, \mathrm{d}x\, \mathrm{d}a}{\iint I(t,a,x)\, \mathrm{d}a\, \mathrm{d}x + \iint H(t,a,x)\, \mathrm{d}a\, \mathrm{d}x}}$$

A NonLocal Epidemic Model – Numerical Integrations

$$\left\{\begin{array}{rcl}
\partial_t S + \partial_a S + \operatorname{div}_x (v_S\, S) + \mu_S\, S & = & -\iint \rho\, I \,\mathrm{d}\alpha\, \mathrm{d}\xi\; S \\
\partial_t I + \partial_a I + \operatorname{div}_x (v_I\, I) + \mu_I\, I & = & \iint \rho\, I \,\mathrm{d}\alpha\, \mathrm{d}\xi\; S - \kappa\, I - \vartheta\, I \\
\partial_t H + \partial_a H + \mu_H\, H & = & \kappa\, I - \eta\, H \\
\partial_t R + \partial_a R + \operatorname{div}_x (v_R\, R) + \mu_R\, R & = & \vartheta\, I + \eta\, H
\end{array}\right.$$

Neglect the aging terms $\partial_a S, \partial_a I, \partial_a H, \partial_a R$ on short time intervals

Neglect the movement terms $\operatorname{div}_x (v_S\, S), \operatorname{div}_x (v_I\, I), \operatorname{div}_x (v_R\, R)$

A NonLocal Epidemic Model – Numerical Integrations

$$\left\{\begin{array}{rcl} \partial_t S + \partial_a S + \mathrm{div}_x\left(v_S\, S\,\right) + \mu_S\, S & = & -\iint \rho\, I\, \mathrm{d}\alpha\ \mathrm{d}\xi\ S \\ \partial_t I\ +\ \partial_a I\ +\ \mathrm{div}_x\left(v_I\, I\right) + \mu_I\ I & = & \iint \rho\, I\, \mathrm{d}\alpha\ \mathrm{d}\xi\ S - \kappa\, I - \vartheta\, I \\ \partial_t H + \partial_a H + \mu_H\, H & = & \kappa\, I - \eta\, H \\ \partial_t R + \partial_a R + \mathrm{div}_x\left(v_R\, R\right) + \mu_R\, R & = & \vartheta\, I + \eta\, H \end{array}\right.$$

Neglect the aging terms $\partial_a S, \partial_a I, \partial_a H, \partial_a R$ on short time intervals

Neglect the movement terms $\mathrm{div}_x\left(v_S\, S\right), \mathrm{div}_x\left(v_I\, I\right), \mathrm{div}_x\left(v_R\, R\right)$

$$\left\{\begin{array}{rcl} \dot S + \mu_S\, S & = & -\iint \rho\, I\, \mathrm{d}\alpha\ \mathrm{d}\xi\ S \\ \dot I\ + \mu_I\ I & = & \iint \rho\, I\, \mathrm{d}\alpha\ \mathrm{d}\xi\ S - \kappa\, I - \vartheta\, I \\ \dot H + \mu_H\, H & = & \kappa\, I - \eta\, H \\ \dot R + \mu_R\, R & = & \vartheta\, I + \eta\, H \end{array}\right.$$

A NonLocal Epidemic Model – Numerical Integrations

$$
\left\{
\begin{array}{rcl}
\partial_t S + \partial_a S + \mathrm{div}_x (v_S\, S) + \mu_S\, S & = & -\iint \rho\, I \,\mathrm{d}\alpha\, \mathrm{d}\xi\; S \\
\partial_t I + \partial_a I + \mathrm{div}_x (v_I\, I) + \mu_I\, I & = & \iint \rho\, I \,\mathrm{d}\alpha\, \mathrm{d}\xi\; S - \kappa\, I - \vartheta\, I \\
\partial_t H + \partial_a H + \mu_H\, H & = & \kappa\, I - \eta\, H \\
\partial_t R + \partial_a R + \mathrm{div}_x (v_R\, R) + \mu_R\, R & = & \vartheta\, I + \eta\, H
\end{array}
\right.
$$

Neglect the aging terms $\partial_a S, \partial_a I, \partial_a H, \partial_a R$ on short time intervals

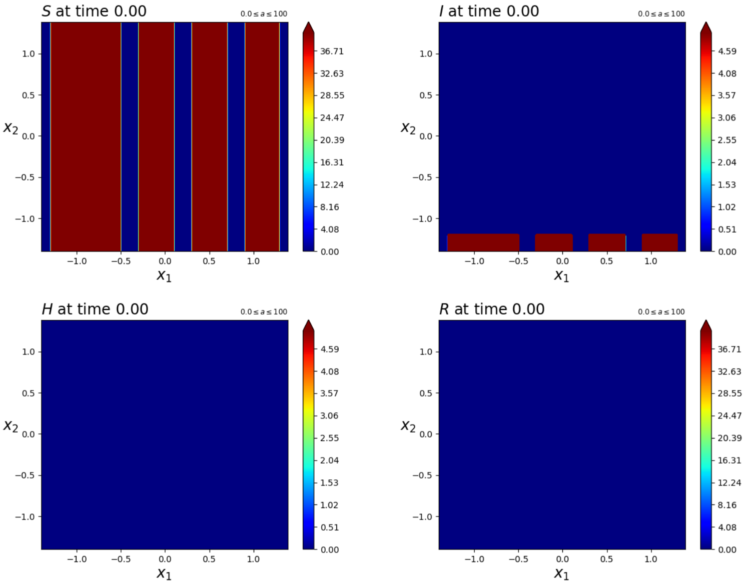
Neglect the movement terms $\mathrm{div}_x (v_S\, S), \mathrm{div}_x (v_I\, I), \mathrm{div}_x (v_R\, R)$

$$
\left\{
\begin{array}{rcl}
\dot S + \mu_S\, S & = & -\iint \rho\, I \,\mathrm{d}\alpha\, \mathrm{d}\xi\; S \\
\dot I + \mu_I\, I & = & \iint \rho\, I \,\mathrm{d}\alpha\, \mathrm{d}\xi\; S - \kappa\, I - \vartheta\, I \\
\dot H + \mu_H\, H & = & \kappa\, I - \eta\, H \\
\dot R + \mu_R\, R & = & \vartheta\, I + \eta\, H
\end{array}
\right.
$$

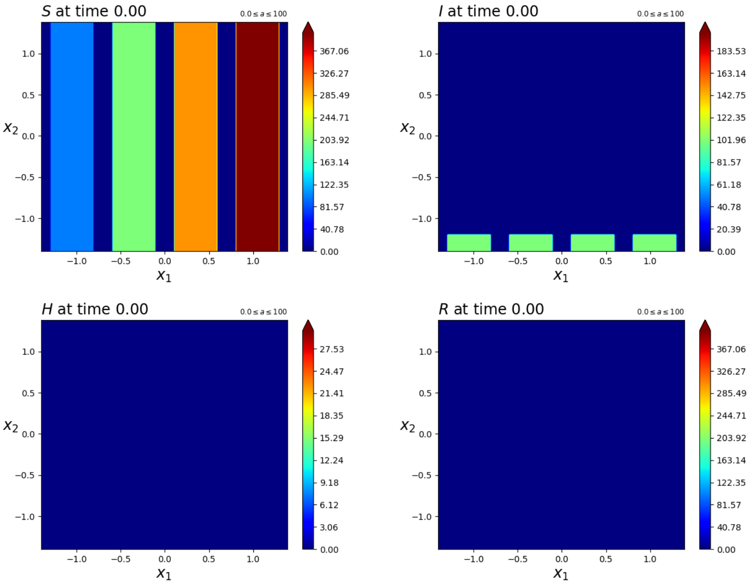
with parameters *"inspired"* by Italian data

4 Age classes: $a < 40\,, \quad 40 \leq a < 60\,, \quad 60 \leq a < 80\,, \quad 80 < a\,.$

A NonLocal Epidemic Model – Age

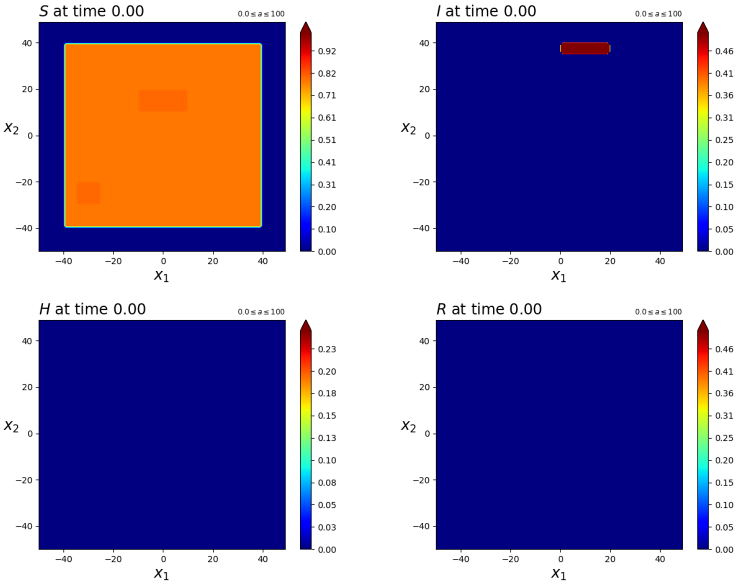


A NonLocal Epidemic Model – Density

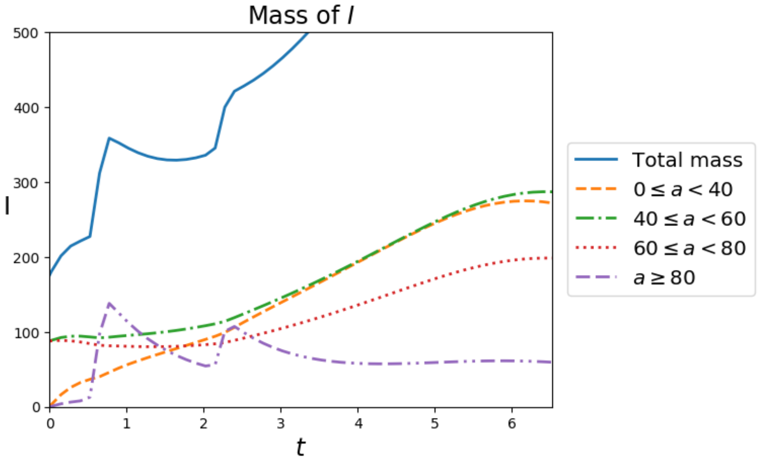


RMColombo

A NonLocal Epidemic Model – Care Homes

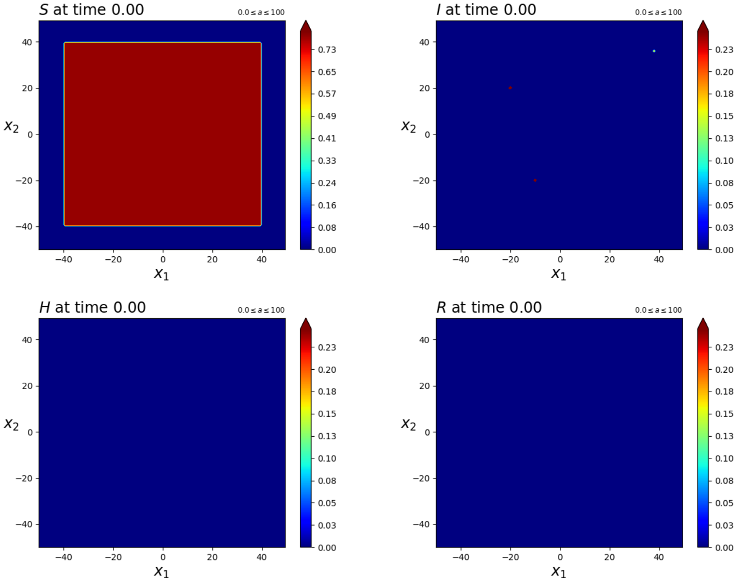


A NonLocal Epidemic Model – Care Homes



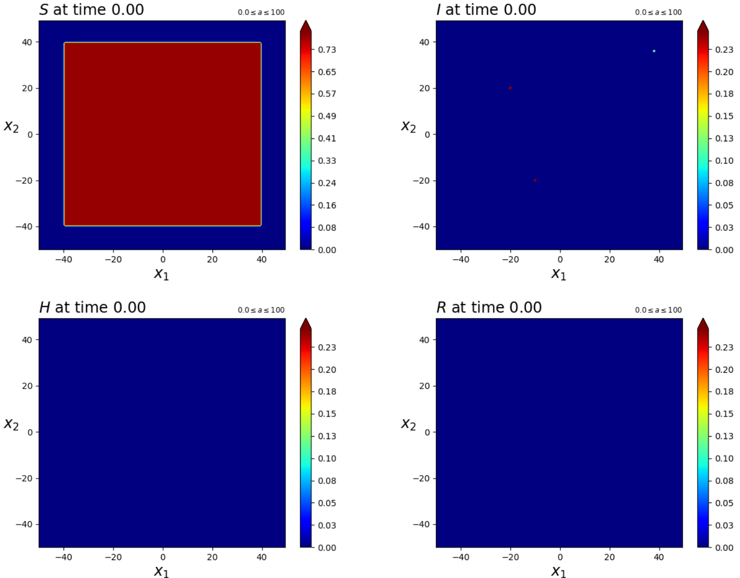
A NonLocal Epidemic Model – A Football Match

No Match



A NonLocal Epidemic Model – A Football Match

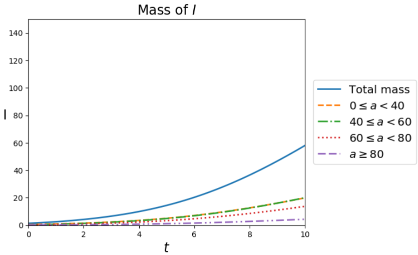
Match for $t \in [0.2, 0.7]$



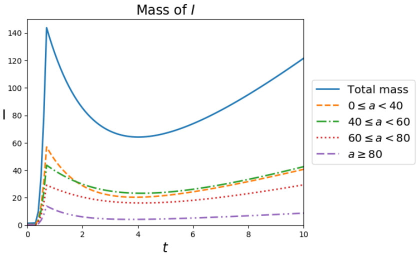
A NonLocal Epidemic Model – A Football Match

I totals

No Match



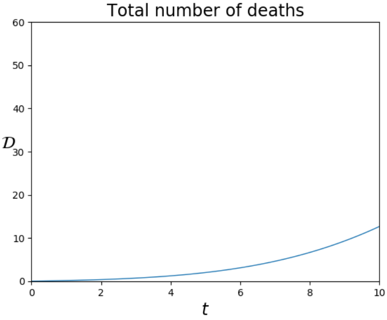
With Match



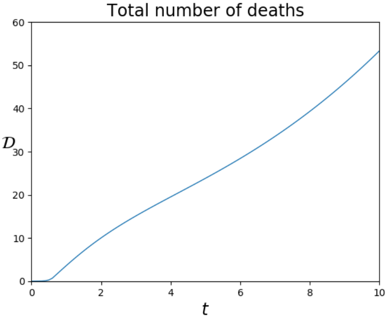
A NonLocal Epidemic Model – A Football Match

Deaths due to the virus

No Match

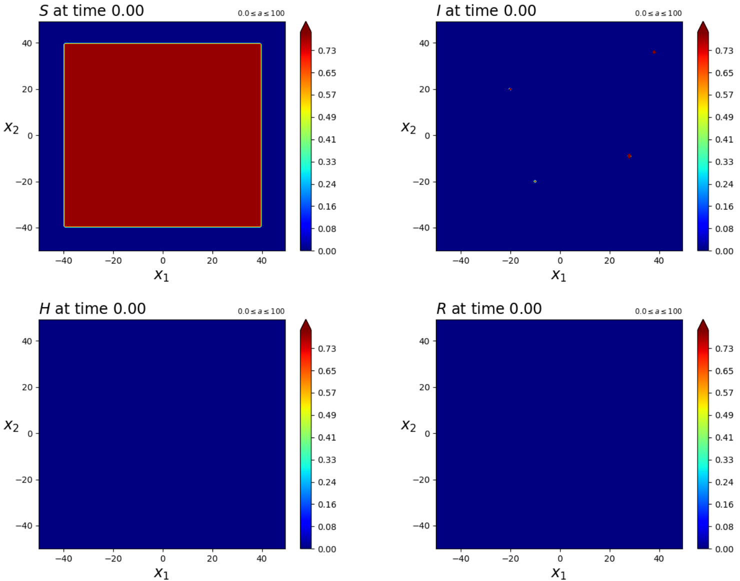


With Match



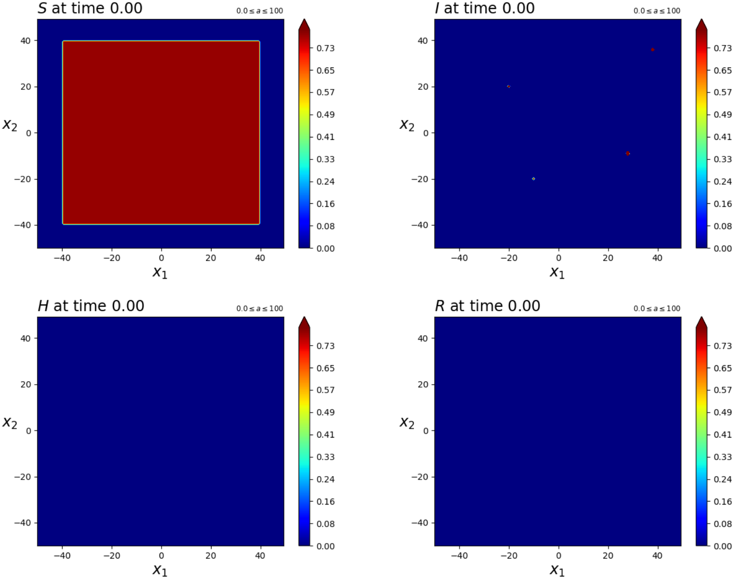
The Relevance of Quarentine

"Low" κ



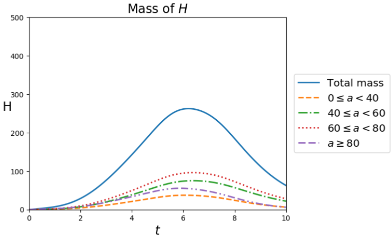
The Relevance of Quarentine

"High" κ

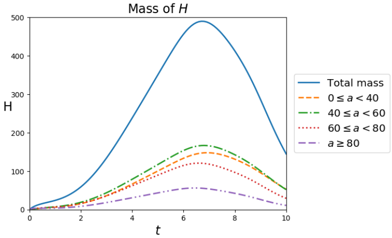


The Relevance of Quarentine

"Low" κ

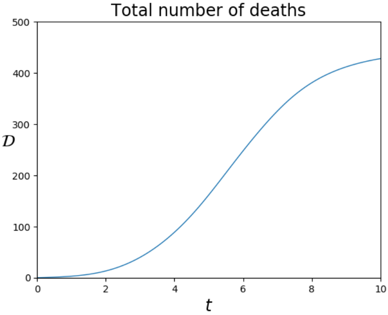


"High" κ



The Relevance of Quarentine

"Low" κ *"High"* κ



Open Problems

- Well Posedness, Stability and Qualitative Properties
- Propagation Speed
- *Ad hoc* numerical algorithms
- Comparing Quarantine Strategies
  Colombo, Garavello
  Well Posedness and Control in a NonLocal SIR Model
  AMOP, To appear
- Optimal Vaccination Policies
  Colombo, Garavello
  Optimizing Vaccination Strategies in an Age Structured SIR Model
  MBE, 2020