Modelling a Multi-Faction Conflict in Multi-Domain Operations

NMSG-197 Symposium on *Emerging and Disruptive Modelling and Simulation Technologies to Transform Future Defence Capabilities*

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MSG-186, Chris Rolfs, Cervus Defence

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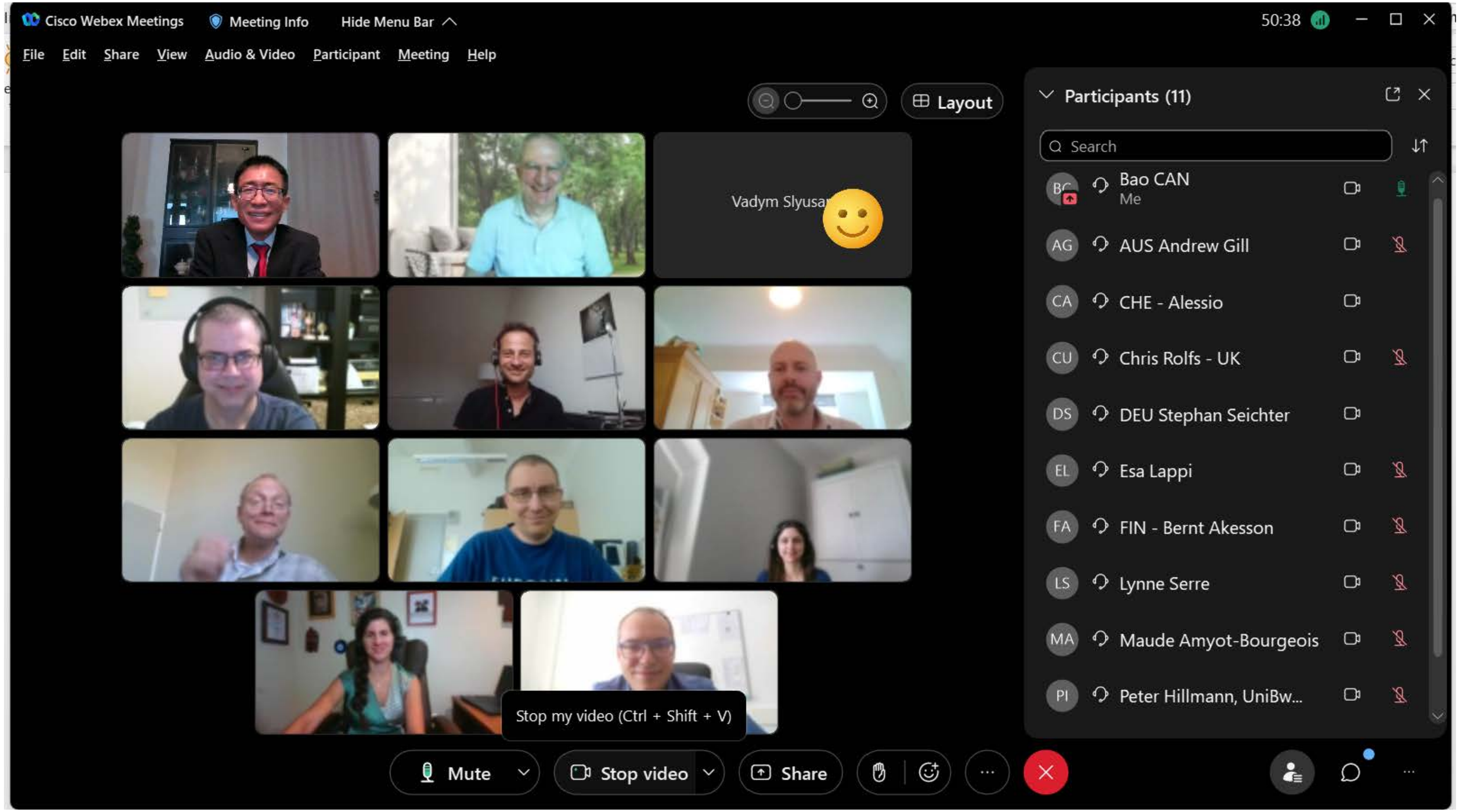
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Introduction

Basic Lanchester Model

$$\dot{B} = -r\,R$$
$$\dot{R} = -b\,B$$

$\dot{f}(t) = \frac{df}{dt}$: Time derivative

$B(t)$: Blue strength at time t

$R(t)$: Red strength at time t

Parameters

$B_0 = B(t_0)$: Initial strength of Blue

$R_0 = R(t_0)$: Initial strength of Red

b: Blue weapon effectiveness on Red

r: Red weapon effectiveness on Blue

Victory condition for Blue:

$$\varphi = \left(\frac{B_0}{R_0}\right)^2 \cdot \frac{b}{r} > 1$$

Multi-Faction Model

Multi-Faction Lanchester Model

$$\dot{B} = -r_b\, R$$
$$\dot{R} = -b\, B - g\, G$$
$$\dot{G} = -r'_g\, R$$

$G(t)$: Green strength supporting Blue at time t

Additional Parameters

$G_0 = G(t_0)$: Initial strength of Green

g: Green weapon effectiveness on Red

$r'_g = r_g - \alpha$, where:

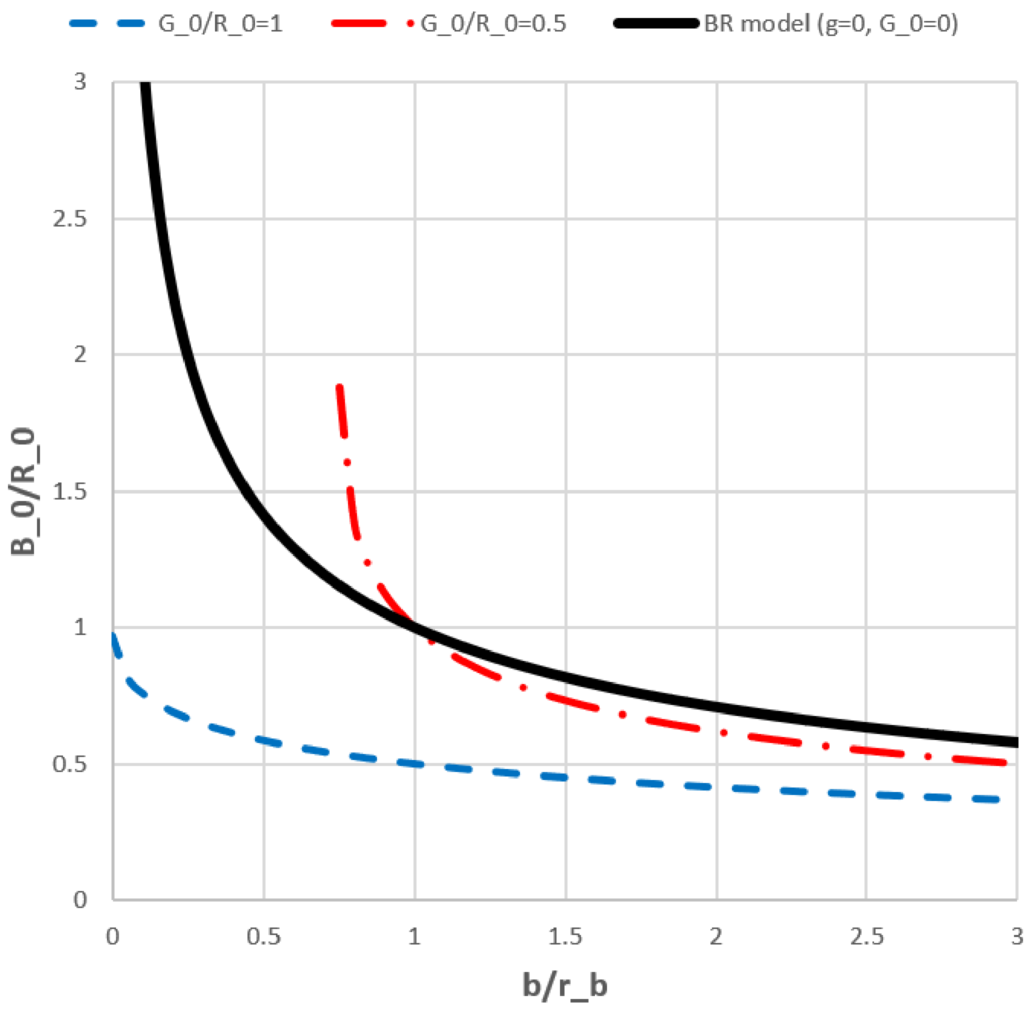
r_g: Red weapon effectiveness on Green

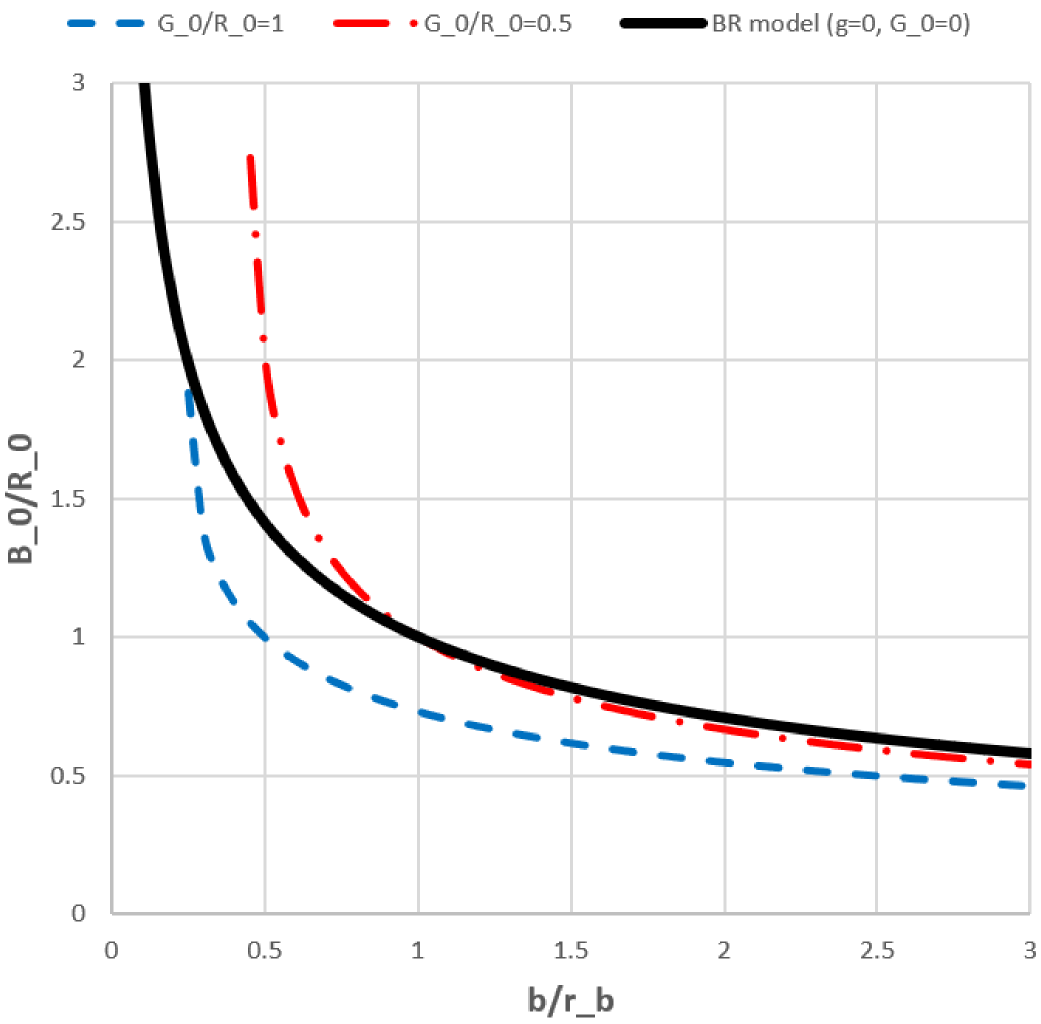
α: Rate of support by Green to Blue

Victory condition for Blue:

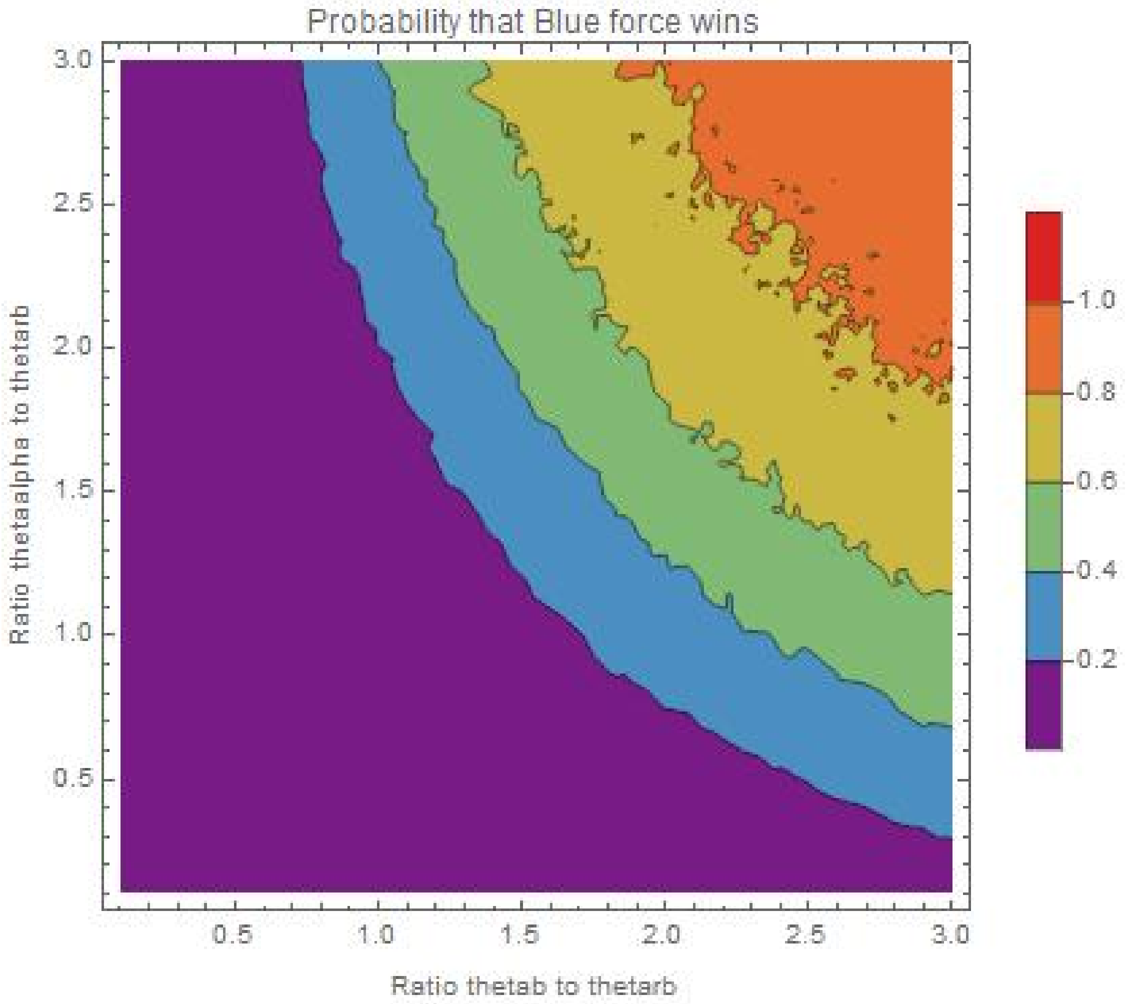
$$\varphi > 1 + \left(\frac{B_0}{R_0}\right)^2 \cdot \frac{g}{r_b}\left(\frac{r'_g}{r_b} - 2\frac{G_0}{R_0}\right)$$

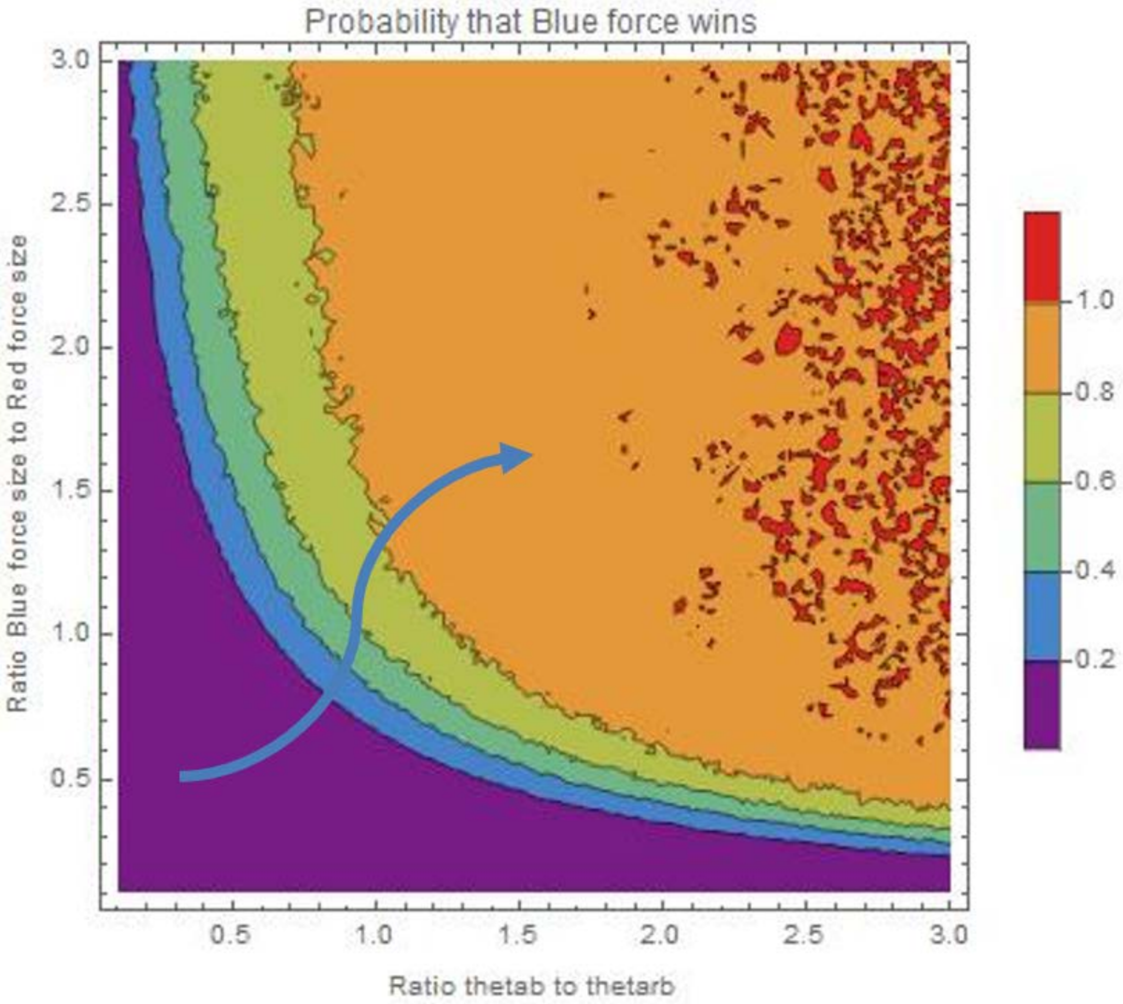
Multi-Faction Model





Multi-Faction Model





Multi-Domain Model

Information (Cyber) Domain†

Blue force composed of a peer-to-peer network of systems:

$$B(t) = B_1(t) + B_2(t) + B_3(t)$$

B_1: Susceptible to cyber attacks
B_2: Infected by cyber attacks
B_3: Immune to cyber attacks

NOTE: Red, Green forces not affected

Implications

Cyber domain: 3 possible transitions:

$B_1 \rightarrow B_2$: Virus infection, rate β_V
$B_2 \rightarrow B_3$: Immunization, rate β_A
$B_1 \rightarrow B_3$: Immunization, rate β_A

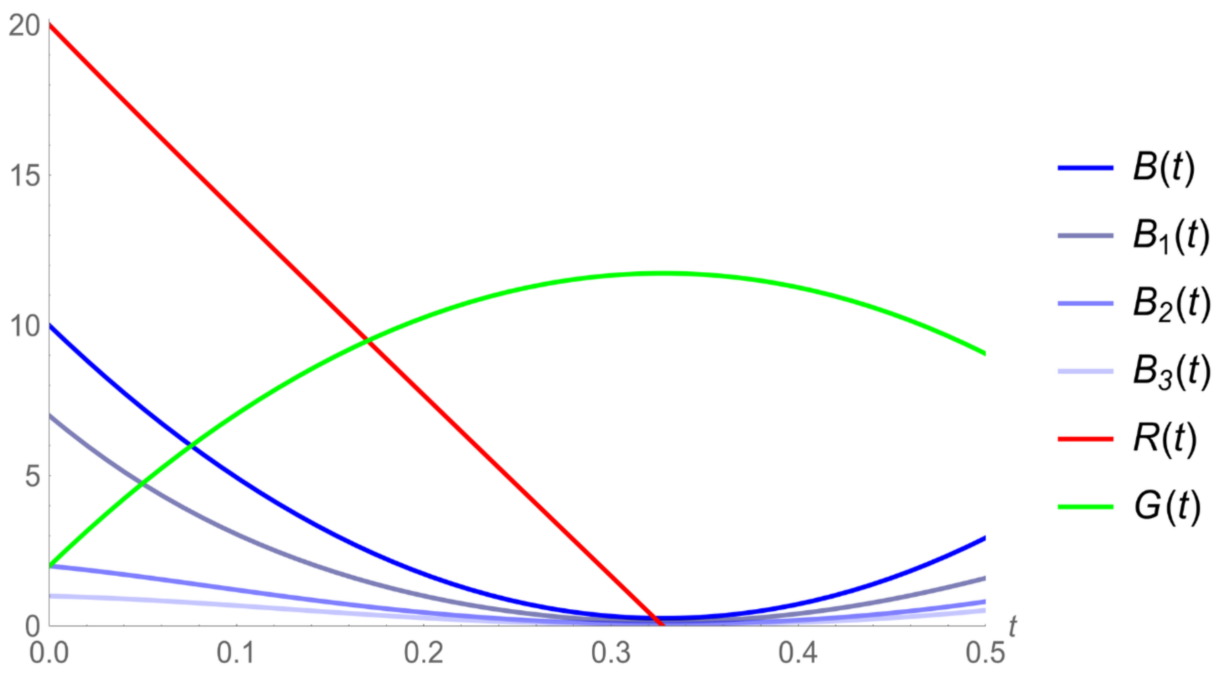
Physical domain: infected systems B_2 are less effective:

$$b_{r,A} > b_{r,V}$$

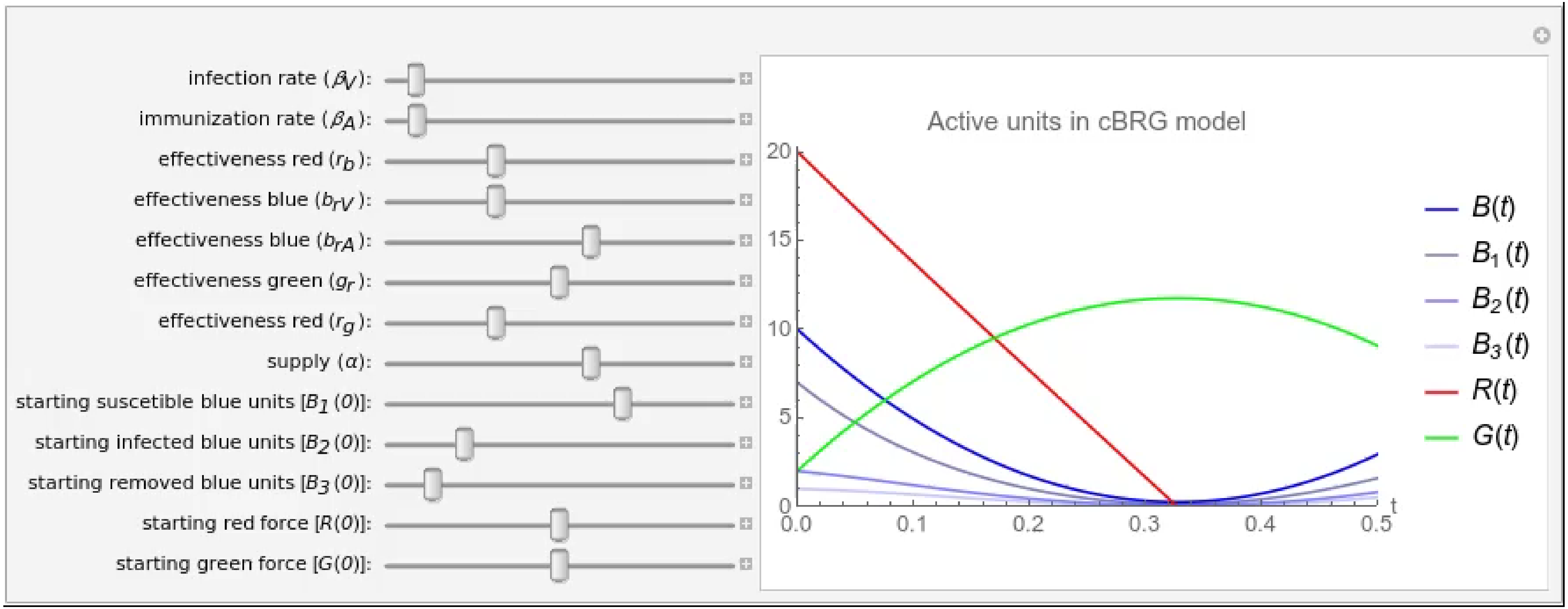
† H. C. Schramm, D. P. Gaver, *Lanchester for cyber: the mixed epidemic-combat model*, Wiley online library, 2013

Multi-Faction, Multi-Domain Model

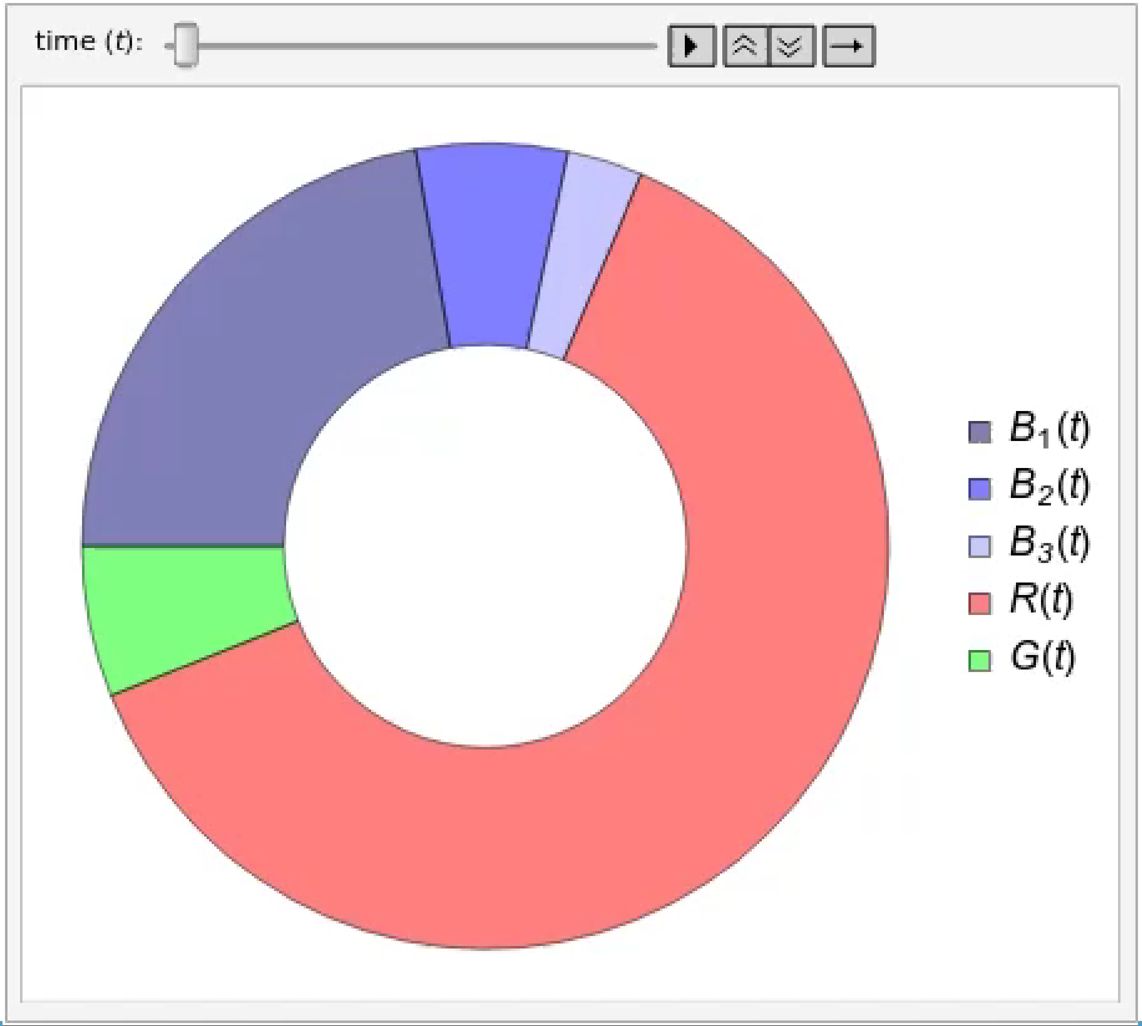
- Conflict in physical/cyber domains
- Numerical solution required
- 13 parameters: $B_1(t_0), B_2(t_0), B_3(t_0), R(t_0), G(t_0),$ $b_{r,A}, b_{r,V}, r_b, r_g, \alpha, g, \beta_V, \beta_A$
- Victory condition?
- Conditions for which cyber attacks play a relevant role?



Multi-Faction, Multi-Domain Model



Multi-Faction, Multi-Domain Model



Data Farming

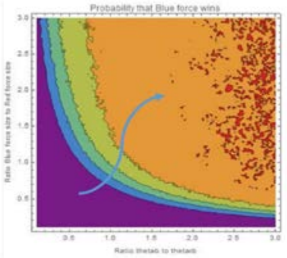
- **Simulation**:
  - Blue Win $= \boldsymbol{MFMDM}(\alpha, b_{r,A}, b_{r,V}, \beta_A, g_r, B_{10}, B_{20}, B_{30}, G_0\,; r_b, r_g, \beta_V, R_0)$
  - Decision parameters x 9, Noise parameters x 4
  - Include **uncertainty**: $g_r \sim \Gamma(k_{g_r}, \theta_{g_r})$ with $k_{g_r} = x_1, \theta_{g_r} = x_2$ etc.
  - Decision **factors** x **14**, Noise parameters x **7**
- **Data Farming**:
  - Build a decision factor **meta-model** robust to noise factors
  - **MOE**: Prob(Blue Win) $= y \approx f(x_1, \dots, x_{14}; n_1, \dots, n_7)$
- **Design of Experiment**:
  - Depends on the analytical **objective** (see next)

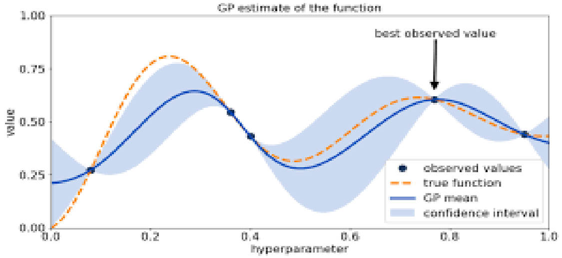
First Analytical Objective

- When we fail, **why** do we fail? (understanding cause and effect):
  - Prob(Blue Win) $= y \approx f(x_1, \ldots, x_{14}; n_1, \ldots, n_7)$
  - 2nd Order $f(\,)$: $\beta_0 + \beta_1 x_1 + \beta_2 x_2 + \beta_{12} x_1 x_2 + \beta_{11} x_1^2 + \beta_{22} x_2^2 + \cdots$
  - **Main** effect (β_1), two-factor **interaction** (β_{12}), **curvature** (β_{22})
- **Design of Experiment**:
  - To fit meta-model: Nearly Orthogonal **Latin Hypercube** (**1003** runs)
  - For Noise factors: OLH (**17** replications)
  - Both are **space-filling** designs
  - Total 17,051 experiments! (Data Farming)
  - US Naval Postgraduate School spreadsheets

Second Analytical Objective

- **What** is required to succeed? (identifying **optimal** decisions):
  - Prob(Blue Win) $= y \approx f(x_1, \dots, x_{14}; n_1, \dots, n_7)$
  - $(x_1^*, \dots, x_{14}^*) = \boldsymbol{d}^* = \textbf{argmax} \iiint f(x_1, \dots, x_{14} | n_1, \dots, n_7) \partial n_1 \dots \partial n_7$
- **Design of Experiment**:
  - Use 17,051 NOLH/OLH design, or … **Sequential** experimental design?!
  - Initial batch design $\boldsymbol{d}_1, \dots, \boldsymbol{d}_n$ which yields $y_1, \dots, y_n$
  - Next design point: $\boldsymbol{d}_{n+1}^* = \text{argmax } EI\{f(d_{n+1} | \boldsymbol{d}_1, \dots, \boldsymbol{d}_n, y_1, \dots, y_n)\}$





- Expected Improvement: balance between **exploit**ation and **explor**ation

Conclusion

Summary

- Probabilistic Lanchester model
- Multi-Faction (Blue, Red, Green)
- Multi-Domain (cyber infection and immunization)
- Derivation of victory conditions:
  - Analytical
  - Numerical

Future Work

- Enhanced Data Farming techniques:
  - Sequential experimental design
  - Automated Machine learning
- Societal domain (public opinion)
- Address high level questions:
  - When we fail, why do we fail?
  - What is required to succeed?

Chris Rolfs
Chief Technology Officer

Cervus Defence
Porton Science Park, Bybrook Road, Porton Down,
Salisbury, SP4 0BF, UK

Tel.: +44 (0) 7932 649 925
chris.r@cervus.ai

NATO
OTAN