

Modelling the Migration and Maturation of Dendritic Cells for Automatic Optimization of Complex Engineering Problems

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Abstract

The metaphor of Migration and Maturation of Dendritic Cells (DCs), in particular, the induced signal pathways to the change of the immunogenic functions of DCs (Martin-Fontecha, Lanzavecchis & Sallusto, 2009) provides important features for the development of the proposed DC-inspired optimization algorithm. Specifically, the quantified capability and behavioral change of DCs (Callard, George & Stark, 1999) of the classical DC models (Caetano Reis, 2006), namely, (i) ontogeny of DC, (ii) the selectively up-regulation of markers (of DC subsets), (iii) the level of threat (of the antigen), (iv) production of chemokine and cytokine, (v) transcription factors, and (vi) the effector functions of DCs underpin a highly autonomous control mechanism for the evolution of the optimal solution(s).

In the proposed autonomous optimization framework, a multi-agent system is developed as described in (Lee & Lau, 2012) incorporating the following DC-inspired philosophies,

- Compartmental interaction and communication of agents.
- Potential threat of solutions is scaled as DCs perform in the host tissue, as well as the measurement of the fitness of the solution(s).
- Synergetic signal cascading (i.e. cytokine production) (Ricart et al., 2011) is adopted to facilitate the solution development process with self-governing characteristic.
- Effector functions are defined to gauge the quality of solution during the solution development (for example, to recruit more DC subsets and re-generating more candidate solutions as depicted in Fig.1).

In the proposed framework (as depicted in Fig. 2), each artificial DC uptakes the characteristics of an antigen (or a permutation) for assessing the level of “fitness” and “threat” of the solution, which are critical to the signal production and forthcoming pathways. Similar to the classical optimization algorithm, “fitness” refers to the optimality for the given objective functions. Whilst the “threat” introduced in the proposed DC-inspired optimization algorithm is quantified by the virulence factors (to the domains), number of iterations or number of replications. These quantified “threat” perhaps ruining the quality of solutions instead of the measurement of “fitness”.

Further enhancing the autonomous control of the proposed framework, immunological signal cascading is adopted. Biologically, signal cascading is represented by a highly dynamic and complex network of immunological signals, namely, chemokines and cytokines. They are predominantly emitted based on the quantified “threat” and “fitness” as abovementioned. The emitted signals and their interactions will further stimulate/suppress the production of chemokine and cytokine. For each of produced signals, it has a specific role in governing the behaviors of the artificial DC subsets, particularly aims at presenting the best for the activation of T-cell. With the inspirations of these immuno-features, a metaphor is anticipated for evolving the optimal solution(s) in the optimization problem. Primarily, the following immunological effector functions are implemented in the proposed DC-based optimization framework,

- Ontology – e.g. recruiting new populations (of artificial DC subsets).
- Phenotype – e.g. changing the permutations (re-capturing the characteristics of the given problem).

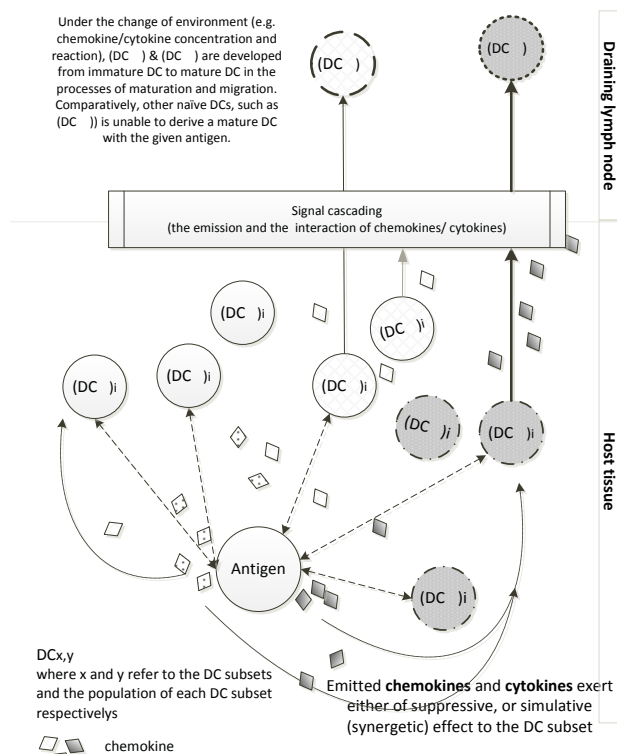


Fig. 1. Schematic diagram of the interactions between DC subsets and chemokine in maturation and migration where DCs are represented by (DC_{x,y})_i and (DC_{x,y})_m

- Population – e.g. the death rate of artificial DC subsets, and the rate of proliferation.
- Migratory behavior.

By modeling DCs' capabilities and behaviors changes in maturation and migration, namely, the quantified level of "threat" and a self-regulated metaphor, the optimal solutions will be resulted. More importantly, the solutions generation can be specific and avoid premature converge which is observed in the classical optimization algorithms.

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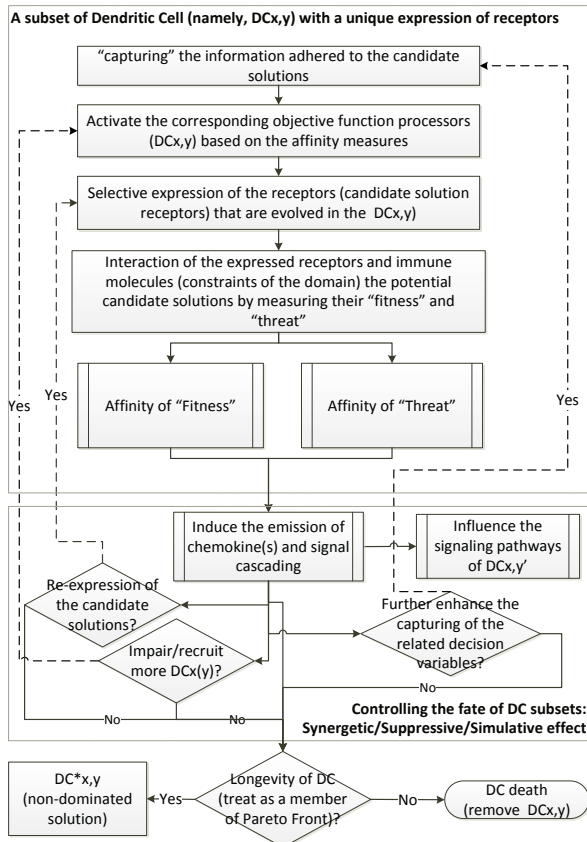


Fig. 2. Proposed automatic DC-mediated Cascading Framework for pursuing an optimal solution – For the attack, each DC subset (denoted by $DC_{x,y}$) acts as a “decision maker” (or “controller”) is equipped with a distinct phenotype for gauging the threat of the candidate solutions (as antigens) based on (i) the emitted signals (as cytokines and chemokine), and (ii) their interactions with the corresponding receptors, and other immune molecules from the neighbouring DC subsets.

In parallel to the studies of classic DC maturation models, impact of the properties changes of “ontogeny” (Population subsets), “phenotype” and “effector” to solutions development are studied in the proposed DC-inspired optimization framework. More importantly, the study reveals some of the unexplored immuno-phenomenon and mechanisms through Matlab simulation.