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P.S. SAPATY[*]

ORGANIZATION OF ADVANCED ISR SYSTEMS BY HIGH-LEVEL NETWORKING TECHNOLOGY

[*]Institute of Mathematical Machines and Systems Problems, National Academy of Sciences of Ukraine, Kyiv, Ukraine

Анотація. *У зв'язку із швидким зростанням світової динаміки у XXI-му столітті передові системи Інтелекту, Спостереження та Розвідки (ІСР) є ключовими для прогнозування, аналізу і протистояння несподіваним ситуаціям та конфліктам. ІСР також є найбільш важливим компонентом військових систем для планування і проведення операцій будь-якої складності та обсягу. У статті обговорюється організація розподілених систем ІСР на основі високорівневої мережевої технології, яка ефективно перетворює світ на просторовий паралельний суперкомп'ютер. Останній дозволяє швидко забезпечувати компактні знання з виникаючих проблем замість величезної кількості первинних даних, які важкко оперативно аналізувати й узагальнювати звичайними методами. Цей матеріал частково доповідався на міжнародних конференціях з ІСР і Систем нічного бачення в Лондоні, Великобританія.*
Ключові слова: *інтелект, спостереження та розвідка, знання, глобальна координація, технологія просторового захоплення, мобільный інтелект, динамічні операційні інфраструктури, нічне бачення.*

Аннотация. *В связи с быстрым ростом мировой динамики в XXI-м столетии передовые системы Интеллекта, Наблюдения и Разведки (ИНР) являются ключевыми для предсказания, анализа и противостояния непредвиденным ситуациям и конфликтам. ИНР также представляет собой наиболее важную компоненту военных систем для планирования и ведения операций любой сложности и охвата. В статье обсуждается организация распределенных систем ИНР на базе высокоуровневой сетевой технологии, эффективно превращающей распределенный мир в параллельный пространственный суперкомпьютер. Последний позволяет быстро предоставлять компактные знания по возникающим проблемам вместо огромного количества первичных данных, которые трудно оперативно анализировать и обобщать обычными методами. Данный материал частично докладывался на международных конференциях по ИНР и Системам ночного видения в Лондоне, Великобритания.*
Ключевые слова: *интеллект, наблюдение и разведка, знания, глобальная координация, технология пространственного захвата, мобильный интеллект, динамические операционные инфраструктуры, ночное видение.*

Abstract. *With the world dynamics growing rapidly in the XXIst century, advanced Intelligence, Surveillance and Reconnaissance (ISR) systems are becoming of paramount significance to predict, analyze and withstand unexpected situations and conflicts. ISR is also the most important component of military systems for planning and management of operations of any complexity and coverage. The paper discusses organization of large distributed ISR systems based on a high-level networking technology effectively converting the distributed world into a parallel spatial supercomputer. The latter allows us to quickly obtain concise knowledge on the problems occurred instead of a huge amount of raw data which is difficult to analyze and generalize by conventional means. This material has been partially reported at recent international ISR and Night Vision conferences in London, United Kingdom.*
Keywords: *ISR, knowledge, global coordination, spatial grasp technology, spatial pattern-matching, mobile intelligence, dynamic operational infrastructures, night vision.*

1. Introduction

The known failures of intelligence in world hot points often result from the incapability of piecing together numerous scattered facts and seeing the overall picture. Such global vision should be provided not only during but rather ahead of real time, in order to win, progress, and even survive.

The existing works in the area of Intelligence, Surveillance and Reconnaissance (ISR) will be outlined, and a new distributed networking technology will be revealed that can help solve many ISR problems. The approach is based on holistic and gestalt principles rather than traditional interoperability organizations, allowing us to grasp integral spatial solutions on top semantic level, abstracting from insignificant details shadowing important decisions which should be done quickly.

While traditional ISR systems usually answer the questions of "what," "when", and "where", the advanced ISR under the technology presented can effectively deal with "how" and "why" being among main goals of the ISR Joint Force 2020 concept currently being discussed worldwide.

Exemplary ISR-related scenarios expressed in a special high-level language will be exhibited and explained confirming viability of the approach offered.

The material presented in this paper has been partially reported at two ISR and one Night Vision conferences in London, Great Britain [1–3].

2. Intelligence, Surveillance and Reconnaissance (ISR)

ISR is defined as an activity that synchronizes and integrates the planning and operation of sensors, assets, and processing, exploitation, and dissemination systems in direct support of current and future operations. This is an integrated intelligence and operations function [4].

2.1. Global ISR

The ISR systems are growing internationally and globally [5–7]. Distributed over large territories, they consist of many interacting elements which should work together as an integral goal-driven system. Global ISR involves a networked system of systems operating in space, cyberspace, air, land, and maritime domains, as in Fig. 1. These systems include planning and direction, collection, processing and exploitation, analysis and production, and dissemination capabilities linked together by communication architecture.

Fig. 1. Global ISR systems

2.2. ISR Joint Force 2020

The most advanced ISR concept, ISR Joint Force 2020 [8], is focused on networked joint ISR solutions rather than traditional platform-centric sensors and processing, exploitation, and dissemination (PED) methods. It should encourage the integration and innovation of multiple sensors to provide the fidelity and redundancy required to support rapid and sound decision-making. The following main factors, named in [8], are driving the need for ISR Joint Force in 2020:

a) Lack of Common Data Standards. ISR systems, due to the way they are developed, fielded, and operated, frequently produce data that is not compatible with data derived from other ISR or combat systems.

b) Disjointed Management of the ISR Force. The current joint force of ISR personnel, sensors, platforms, and networks is so vast, diverse, and distributed that managing their effective employment represents a large and growing challenge.

c) Parochial ISR Architectures. While there is certain progress in system and data interoperability, an ISR architecture that would allow data to be moved from all domains and across multiple platforms and sensors rapidly and effectively still does not exist. Proprietary systems, networks, formats, and protocols impede integration and interoperability.

d) Increasing Threats to Systems and Communications. The ISR Joint Force 2020 will face increasingly sophisticated adversaries capable of challenging the ability to operate effectively with assured command and control in every domain. The lethal and nonlethal threats to platforms, sensors, communications, and infrastructures continue to grow rapidly in sophistication and scale.

2.3. New ISR Approaches Required

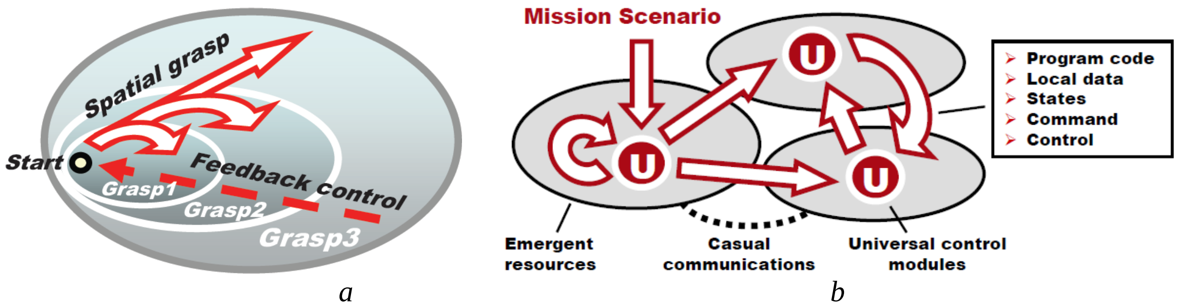
To implement this new and in many cases revolutionary ISR vision, an introduction of radically new paradigms, strategies, and concepts with the use of advanced networking models and technologies capable of operating in dynamic, unpredictable, and often hostile environments will be needed. The rest of this paper is dealing with the Spatial Grasp Ideology and Technology [9–13], already tested on numerous networked applications, which can offer a universal theoretical and practical solution for advanced ISR systems of the 21st century.

3. Spatial Grasp Technology (SGT)

We are briefly describing here a high-level networking ideology and technology that can solve a variety of ISR problems of any complexity and world coverage in a highly parallel and fully distributed manner.

3.1. Controlled Grasp of Distributed Spaces

The key SGT ideas are symbolically shown in Fig. 2.



a *b*

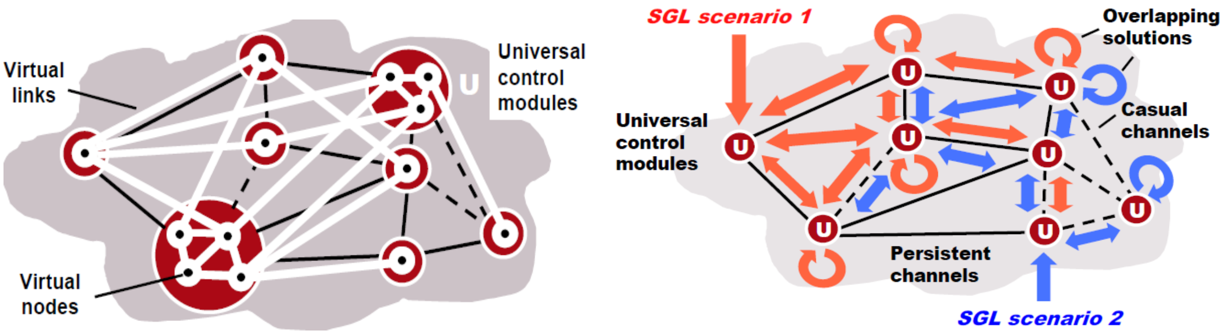
Fig. 2. SGT basics: a) Seamless controlled spatial grasp;
b) Self-evolution & spatial matching of SGT scenarios via interpretation network

SGT is based on integral, seamless navigation & coverage & conquest of physical and/or virtual spaces (Fig. 2*a*). It has philosophical and psychological background reflecting how people plan, comprehend, and control complex operations, with the human mind supposedly operating in overlapping waves, streams, states and structures of consciousness and their combinations [14]. It also pursues holistic and gestalt [15, 16] philosophy, contrary to the traditional vision of intelligence through interaction of multiple parts, or agents, stemming from [17]. SGT, also known as over-operability approach [18], is trying to formalize the unique capability of mind to comprehend whole first while treating parts second, as a derivative of the whole.

3.2. How SGT Operates

SGT in general operates as follows. A network of universal control modules U embedded into key system points (humans, robots, sensors, mobile phones, etc.) collectively interprets high-level mission scenarios in a high level Spatial Grasp Language (SGL) [9–13], see Fig. 2*b*. Capable of representing any parallel and distributed algorithms, these scenarios can start from any node, covering at runtime the whole world or its parts needed with operations and control.

The spreading scenarios can create knowledge infrastructures arbitrarily distributed between system components (robots, sensors, humans), as in Fig. 3*a*. Navigated by same or other scenarios, these can effectively support distributed databases, C2, situation awareness, and autonomous decisions, also simulate any other existing or hypothetic computational and/or control models. SGL scenarios can cooperate or compete in a networked space as overlapping fields of solutions, as in Fig. 3*b*.



a *b*

Fig. 3. Operation of SGL scenarios in distributed spaces: a) Creation of spatial infrastructures; b) Spatial interaction of different scenarios

The distributed dynamic network of local SGL interpreters U, which may cover any distributed spaces, the whole world including, can be considered as a radically new type of parallel supercomputer, which can have any (including runtime changing) networking topology and operate without any central resources. SGL scenarios, representing active spatial (integral, holistic, gestalt-like) patterns rather than traditional programs, can be injected into this spatial supercomputer from any its node, subsequently self-spreading, replicating, modifying, interlinking, etc. and covering & matching it with proper operations and control in a virus-like mode.

3.3. Spatial Grasp Language (SGL)

SGL (with its details in many existing publications, for example [9–11]) allows us directly move through, observe, and make any actions and decisions in fully distributed environments (physical, virtual, executive, or combined). It has universal recursive structure (shown in Fig. 4) capable of representing any parallel and distributed algorithms operating over spatially scattered data.

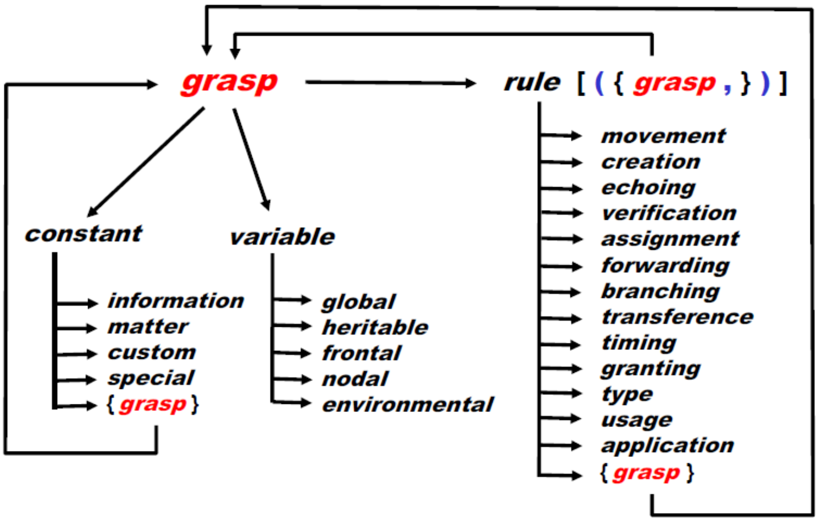


Fig. 4. The SGL universal recursive syntax

The SGL scenario develops as parallel transition between sets of progress points (props), which may be associated with different physical or virtual locations in distributed worlds. Any sequential or parallel, centralized or distributed, stationary or mobile algorithm operating with information and/or physical matter can be written in SGL at any levels.

3.4. SGL Networked Interpreter

SGL interpreter (with details, say, in [9–13]) consists of a number of specialized modules handling & sharing specific data structures. A backbone of the distributed interpreter is its spatial track system providing global awareness & automatic C2 over multiple distributed processes, also creating, managing (and cleaning when becoming not needed) the distributed information and control resources.

The distributed SGL interpreter, which may have any number of nodes, up to millions or even billions and distributed worldwide, can operate with dynamic and changeable topology with the number of interactive nodes varying during the scenario evolution, with many scenarios (injected from different nodes) operating at the same time and in the same networked space, sharing spatial resources.

The SGL interpreters can be embedded into the world fabric on agreements, or can (all or some) be hidden, stealthy, depending on the applications. Due to the full interpretation of SGL scenarios and their virus-like absolute mobility nature and capabilities, the technology can be used in highly dynamic, asymmetric, critical situations, where, say, the missions should always survive and fulfil objectives, possibly, even by any means.

4. Global Surveillance Examples with Spatial Pattern-Matching under SGT

The most general solution of distributed ISR problems under SGT is shown in Fig. 5.

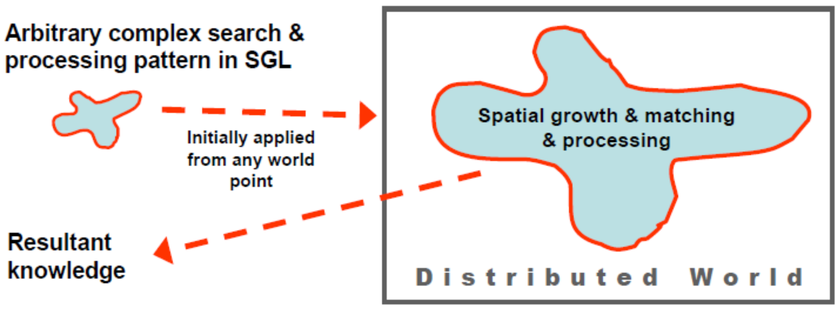


Fig. 5. Solution of distributed ISR problems in a spatial pattern growth & matching mode

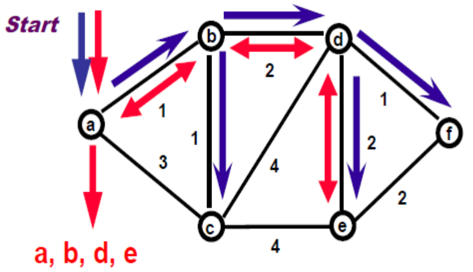
An SGL scenario to solve any distributed ISR tasks is represented as an active integral pattern rather than a traditional program, sequential or parallel. Expressed in the recursive SGL syntax, this pattern does not process separated data in a usual way, but rather spatially covers, matches, and integrates with the data networks, bringing the needed operations and control directly into them.

This allows us to find solutions of various problems directly in complexly interlinked large data spaces, instead of first digging separately in local databases and then trying to combine local results, which may be extremely hard computationally, also time consuming. SGL active spatial patterns can do this holistically, in a "single breath", with possible time reduction of orders of magnitude in comparison with other existing network-supported methods.

The following are some examples of solving ISR-related problems using spatial SGL patterns, obtaining higher-level knowledge from large amounts of scattered and interrelated raw data.

4.1. Shortest Path

It is supposed that there exists unlimited number of scattered nodes with links between different nodes having weights, and it is necessary to find shortest path between certain pair of nodes. An example of such network with weighed links and active pattern expressed in SGL to be applied to the network in order to find such path between nodes and a and e are shown in Fig. 6.



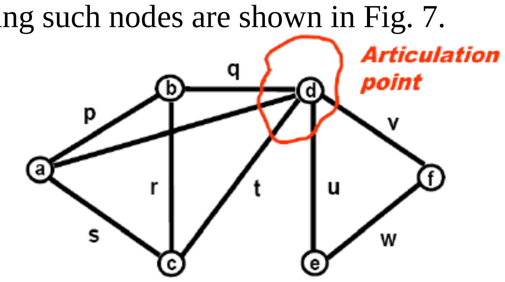

```
frontal (Far, Path); nodal (Distance, Before); hop (a);
sequence (
1  (Distance = 0;
    repeat (
      hop (all links); Far += LINK; or (Distance == nil, Distance > Far);
      Distance = Far; Before = BACK)),
2  output (Path = NAME;
      repeat (hop (all links); BACK == Before;
        Path &= NAME; if (NAME = e, (Path; stop)))) )
```

Fig. 6. Finding shortest path between given nodes

The SGL pattern, which can initially be applied from any node, has two main parts: (1) shortest path tree (SPT) creation starting from node a and covering all other nodes, and (2) shortest path collection starting from node a again and ending in node e, using the created SPT. The obtained result (a, b, d, e) will be issued from node a. The solution has been found without any central resources, by spatial evolution, coverage, and matching of the SGL pattern with the distributed network of Fig. 6, supposing that all network nodes (or their groups) are served by individual language interpreters, which can communicate with each other.

4.2. Weakest, or Articulation, Points

This example relates to finding such single nodes of the network which, when removed, split the network into disjoint parts. An example of the network to be examined and SGL pattern for finding such nodes are shown in Fig. 7.




```
1  nodal (Mark);
   hop (all nodes); COLOR = NAME; Mark = 1 ;
   and ( (hop (random, all links);
2       repeat (grasp (Mark == nil; Mark = 1); hop (all links))),
3       (hop (all links); Mark == nil) ,
4       output (NAME) )
```

Fig. 7. Finding all articulation points

The active SGL pattern for finding articulation points consists of four parts performing the following operations:

1) Starting in each node with personal color, marking it;

2) Parallel marking of all accessible network nodes with this color from a randomly chosen neighbor, excluding itself from the marking process;

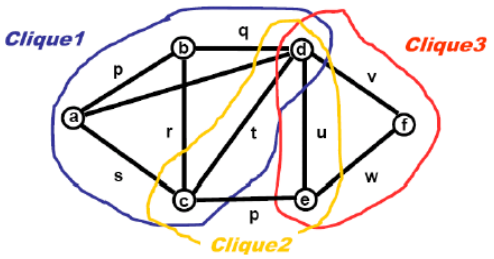
3) Checking if there are unmarked neighbors of the starting node;

4) Outputting the node's name if yes.

The only result for this network, node d, will be issued by this node itself taking into account that nodes are supported by communicating SGL interpreters. The result, of the rank of knowledge, has been obtained by parallel spatial activity of potentially huge amount of raw data.

4.3. Strongest Substructures, or Cliques

This example relates to finding cliques in distributed networks, which are maximum subgraphs of a graph where every node has links with all other nodes of this subgraph. In contrast to articulation points, cliques may be considered as the strongest parts of graphs/networks. An example of the network to be analyzed for cliques and active SGL pattern for finding all of them, are shown in Fig. 8.




```
1  frontal (Clique); hop (all nodes); Clique = NAME ;
2  repeat (hop (all links); not belong (NAME, Clique);
          if (and parallel (hop (any links, Clique)),
             if (BACK > NAME, Clique &= NAME, done), fail)) ;
3  if (length (Clique) >= 3, output (Clique))
```

Fig. 8. Finding all cliques

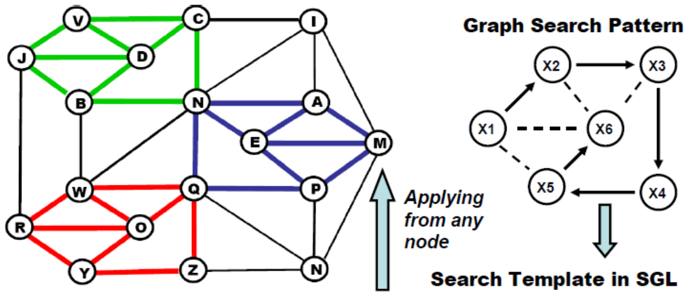
The SGL pattern consists of the three parts performing the following:

1) Starting in each node, defining spatial variables;

2) Self-spreading with replication, while growing potential clique in a unique node order, until possible;

3) Outputting the clique grown with the threshold size given, in the last node included into the clique.

The results issued in nodes d, e, and f will, respectively, be as: (a, b, c, d), (c, d, e), and (d, e, f). These results, treated as knowledge similar to the previous two examples, have been obtained by parallel spatial activity of potentially huge amount or networked raw data supported by distributed SGL interpreters.




```
hop (all nodes); frontal (Match) = NAME;
5 (all #; notbelong (NAME, Match)); append (NAME, Match));
advance (any # sequence (Match : (1, 5, 6, 2, 3, 6))); OUT = Match
```

Fig. 9. Finding all structural matches by arbitrary patterns

4.4. Any Structures in Any Networks

Using SGT, it is easy to find any substructures in any networks in a parallel and fully distributed mode. Fig. 9 shows how arbitrary graph pattern with variables Xi in its nodes can be represented in SGL and spatially matched with arbitrary network.

For the graph template at the right, and its SGL coding below as an active self-matching template, the following solutions for the variables X1 to X6 will be found in the network at the left:

(X1, X2, X3, X4, X5, X6) → (J, V, C, N, B, D), (M, A, N, Q, P, E), (R, W, Q, Z, Y, O).

The obtained knowledge is again based on parallel activity of the whole data network, with all solutions found without any central facilities or control.

4.5. Global Surveillance with Targets Collection and Impact

This example deals with the distributed discovery and collection of information on possible hostile objects, or targets, using the interlinked network of SGL interpreters embedded in different military units distributed throughout the operational theatre, as shown in Fig. 10.

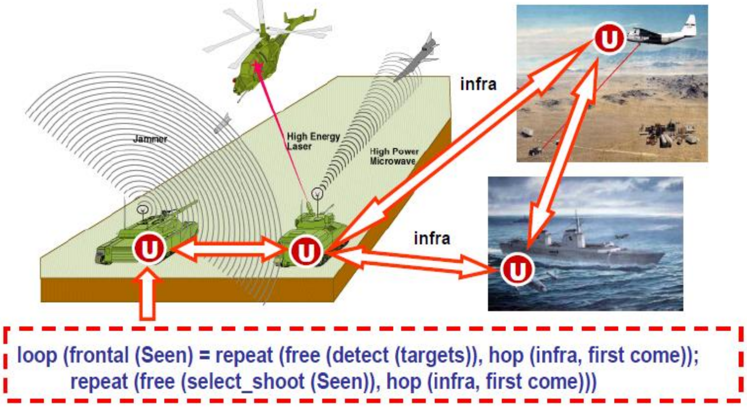


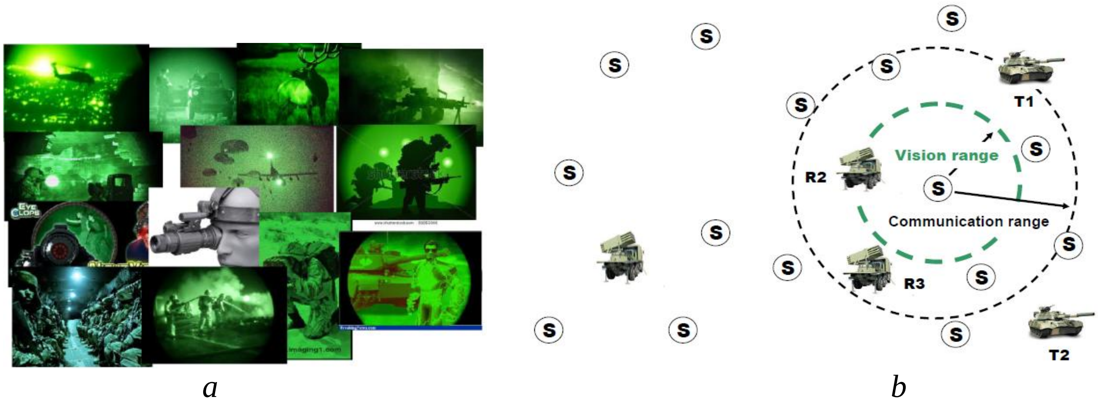
Fig. 10. Global surveillance with distributed collection & dissemination & processing of targets

The SGL self-evolving pattern-scenario (shown in the figure below), starting from any component (this may be especially vital as any unit can potentially be destroyed on a battlefield and at any time), provides global collection of targets and their subsequent dissemination back to the units, the latter deciding themselves which targets to shoot individually or which to ignore.

4.6. ISR with Distributed Night Vision

Under SGT, multiple communicating sensors can be distributed throughout any regions, operating altogether as an integral spatial brain which can provide holistic vision of the operational theatre. Such brain can help with solving urgent ISR tasks even in case of reduced vision, say at night or in bad weather, compensating the insufficient or corrupt sensor data with the enhanced intelligence of the whole system, thus allowing us to have a much clearer (say, repeated and integrated from different angles) picture of both separate objects and the theatre as a whole.

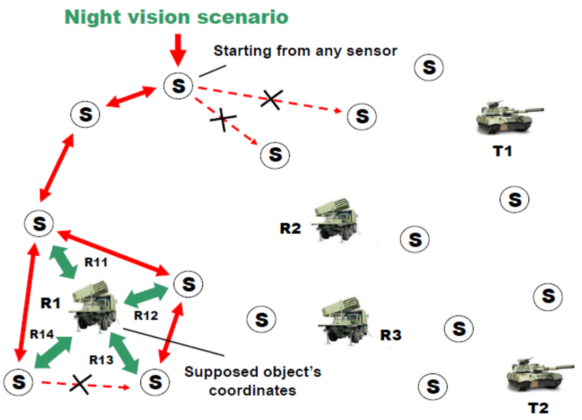
For the night vision, its different equipment and scenario shots are collected in Fig. 11*a*, and an example of scattered military units and sensors throughout the theatre, with individual vision and communication ranges of the sensors, is depicted in Fig. 11*b*.



a *b*

Fig. 11. Night vision: a) Night vision equipment shots; b) Exemplary theatre with scattered sensors

Multiple spatial vision of a given single object. In Fig. 12, a case is shown where information of a target given by its coordinates (R1 in our case), is being collected by all sensors covering it by their vision ranges, thus allowing us to obtain its enhanced, multiple image from different angles and different sensor locations.

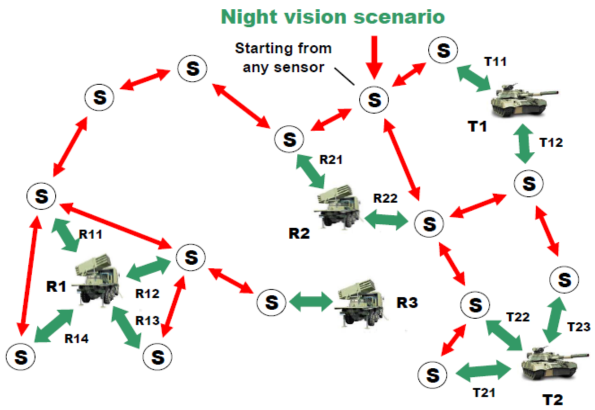



```
fontal (Target_coord = ..., Vision_range = ...,
        Communication_range = ...,
        Distance = distance (Target_coord, WHERE));
Object_seen = merge (
  repeat (
    hop_first (Communication_range);
    Distance1 = distance (Target_coord, WHERE);
    If (Distance1 < Vision_range,
      (free (image (Target_coord)), Distance = Distance1),
      (Distance1 < Distance; Distance = Distance1))))
```

Fig. 12. ISR with multiple vision of a single object

To do this, the shown SGL scenario can start from any sensor, and then moves through their network defined by sensor communication ranges to the region where sensors, if exist, can potentially see the object (i.e. R1) by their vision ranges, with activating all such sensors. The returned resultant image in multiple, differing, copies of R1 got from four sensors will be as: (R11, R12, R13, R14). This final result will be returned to the sensor where the SGL scenario started. If needed, these four images of R1 can merge into one, integral image, which may happen to be even better than the one received from a single sensor at daytime.

Spatial Vision of the Whole Theatre in SGL. To see the whole theatre equipped with night vision sensors with multiple images of the same objects seen from different sides and angles, if located within vision ranges of more than a single sensor, we may use the solution shown in Fig. 13.




```
fontal (Vision_range = ...,
        Communication_range = ...);
Objects_seen = collect_merge (
  repeat (
    hop_first (Communication_range);
    free (images (Vision_range)), stay))
```

Fig. 13. ISR with multiple vision of all objects

The SGL scenario-pattern can start, same as for the previous case, from any sensor, subsequently covering in a parallel wavelike mode the whole set of sensors via direct communications within their communication ranges. The returned resultant image of the whole theatre with existing R1, R2, R3, T1 and T2 units there will be as follows : (R11, R12, R13, R14) , (R21, R22), R3, (T11, T12), (T21, T22, T23). It will be collected in the same sensor the SGL scenario started.

4.7. Tracking Moving Objects by Mobile ISR

With distributed sensor networks spread throughout civil or military operational theatres, it is possible to solve many more and much complex tasks than the shown above. Among them-runtime surveillance of multiple objects moving through distributed spaces. Fig. 14 shows SGL solution for discovery and tracing of a mobile object using mobile intelligence following the object's physical movement through the whole environment via propagation through virtual space.

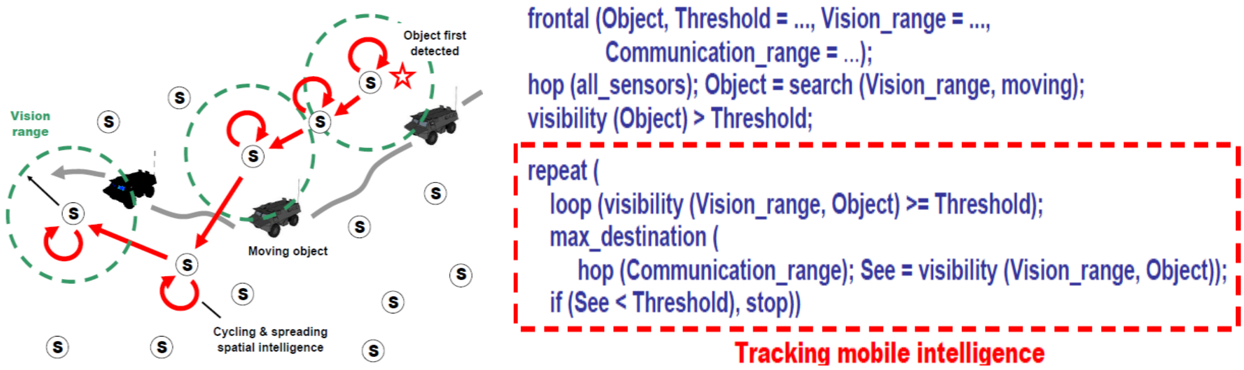


Fig. 14. Tracking of the moving object with mobile ISR technique in SGL

The later is maintained by communicating sensors with automatic handover of the surveillance control when physical object moves to other regions, supervised by other, neighbouring sensors. The neighbouring sensor, which sees best the object disappearing from vision of the current sensor takes the lead, and so on.

4.8. Finding All Virus Sources in Parallel

An example close to the distributed ISR but from a very different field is shown in Fig. 15, where spatial SGL template, applied in all nodes of the computer network, detects existence of viruses in nodes and traces back their spread through the network, while finding all possible virus sources and providing their ordered resultant list (as nodes 6 and 5 in the figure).

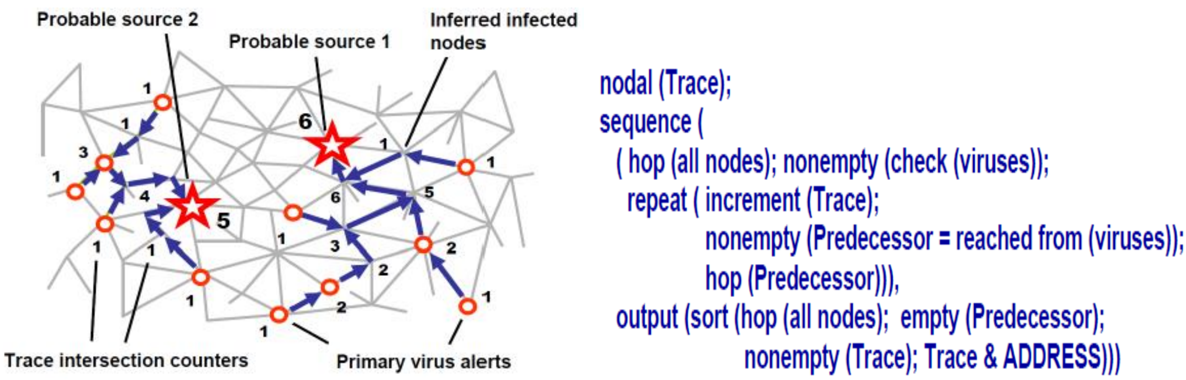


Fig. 15. Finding all virus sources in a computer network by spatial SGL pattern

5. Solving Other ISR Problems

We have demonstrated only elementary examples of using SGT for ISR-related tasks. A thorough analysis is being carried out on the suitability of the approach for solving many other and much broader ISR problems, and on any levels. These can include the ones listed in Section 2.2 in relation to ISR Joint Force 2020 concept, as the reason for its development. We repeat them below followed by the advantages that can be provided by SGT.

a) Lack of Common Data Standards. SGT provides universal representation of high-level knowledge which, if used on top system level, can effectively integrate the whole distributed ISR systems with setting elementary converters between the existing local standards and SGL-based universal representation.

b) Disjointed Management of the ISR Force. SGT provides unified management, simulation and control of large ISR systems, where different components can be manned, unmanned, and/or simulated, with dynamic situation-driven watershed in between.

c) Parochial ISR Architectures. SGT proposes a universal high level architecture for distributed knowledge representation and top decisions on a semantic level, while not rejecting at the same time existing, possibly even primitive architectural solutions at lower levels. -- Thus enriching and empowering the whole system with important originality and diversity, but at the same time obeying global standards.

d) Increasing Threats to Systems and Communications. Due to the full scenario interpretation rather than compilation and unlimited virus-like code mobility, which can self-recover after indiscriminate damages of system components, also capability of work with arbitrary (including casual, unsafe, and runtime changing) communication structures, SGT can effectively withstand existing and forthcoming threats.

6. Conclusions

The Spatial Grasp Technology can effectively establish global control over large distributed systems of any natures, ISR including. It can use distributed and dissimilar ISR facilities in an integral and holistic way, allowing them to work together in a supercomputer mode. This parallel supercomputer can spatially match arbitrary complex search and processing patterns worldwide, producing intelligent knowledge rather than traditional huge collection of raw data, which is difficult to comprehend as a whole. SGT allows us to task and re-task complex missions at runtime, on the fly, quickly responding to changing situations, goals, and environments.

Due to formalized representation of missions in a special high-level language, it becomes possible to effectively automate command and control and broadly use the unmanned components. Based on full interpretation and unlimited mobility of program code in distributed networked environments, SGT has high level or ubiquity, stealthiness and self-recovery. It can be used in both live and simulation modes as well as any combination thereof.

The described approach had been prototyped and tested, via internet including, in different countries and on a variety of networked applications (like distributed interactive simulation, massive collective robotics, critical infrastructure protection, automated command and control, human terrain, and so on). On an agreement, the technology can be quickly ported on any platform needed with the help of a small group of system programmers under the author's guidance. A new patent on the tech is being prepared, a new book too.

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