Space Debris: Between Unity and Fragmentation – Risk as a Static Principle with Dynamic Outcomes

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Abstract

This paper analyses the interrelationship between science, risk, international law and the prevention of collisions between space objects, so as to contribute to progressive development of international law and of an epistemic community invested with a common conceptual and terminological apparatus, as well as to examine interrelated juridical and technical obstacles and opportunities regarding the creation of an informed, uniform and therefore, it is posited, more effective regulatory regime.

To contribute to establishing a common frame of reference, the article presents and explores an analytical and theoretical mapping exercise of some *structural contours* delineating mutual space object relations, positing the common construction of risk and its collective management as central to the asymptotic realization of uniformity in standards concerning space objects, space debris and its removal, and preventing physical interference or collisions. The paper proceeds from scientific insights into collision risk to uncover the extent of the technical notion of risk in this area before briefly examining how risk management mechanisms operate in international law to produce restrictions or permissions regarding future conduct, activities or incidents. Risk emerges as a 'static', i.e. common, principle with 'dynamic', i.e. variable, outcomes that may form the normative foundation of a uniform yet highly adaptive regulatory framework – a principle thus particularly suited to protean conditions in orbital space. Finally, some sketches follow of a heuristic device for envisaging the normative and jurisprudential construction of a static risk principle that can correlatively produce the substantively variable permissive rights and restrictive obligations as may attach to space objects, i.e. output, on the basis of evolving material conditions in orbit, i.e. input.

Keywords: risk, space object, space debris removal, material environment, social milieu, collision prevention, harmful interference.

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'*For a successful technology, reality must take precedence over public relations, for nature cannot be fooled.*'[1]

~ Richard P. Feynman

1. Introduction

International space law seeks to regulate a broadly defined category of technical and scientifically sophisticated human activity. Legal instruments replete with technical equations such as the International Telecommunication Union (ITU) Radio Regulations or the complementary roles of the Legal Subcommittee (LSC) and the Scientific and Technical Subcommittee (STSC) of the UN Committee on the Peaceful Uses of Outer Space (COPUOS) exemplify an inextricability between law, technology and science in regulating space activities. Requirements for interdisciplinary sophistication abound also regarding regulation of manmade objects to prevent potentially harmful physical interference or to guarantee sustainability.

This paper analyses some of the likely issues that may arise due to complex marriage of law, science and technology in attempting to legally manage a material orbital space object population. It proposes and briefly sketches a novel conceptual framework, here termed 'structural analysis', including heuristic, analytical, methodological tools and terminology, which may facilitate cross-disciplinary maturation of an *epistemic community* concerning administration of legal limits to physical use of Earth's orbits.

2. Space Facts and Space Law: Prevention, Risk and Structure

The well-known legal maxim *ex facto sequitur lex*, or *ex facto oritur ius*, expresses that promulgation and application of law should be based on relevant facts: legal consequences attach to particular 'facts', or constellations of such facts, in a more or less certain manner. Jurisprudence evinces various 'doctrines of fact-finding' grappling with quandaries such as qualification of facts; interrelationships of scientific, historical, and legal facts; or even transliteration between 'empirical facts' on the one hand and 'legal facts', fictions, presumptions and burdens of proof on the other. Scientific facts and legal facts often refer to an identical material subject matter or referent object while capturing it in wholly different domain-or discipline-specific terms, methodologies, ontologies, cognitive scripts or modes of thought, so

1 R.P. Feynman, 'Personal Observations on Reliability of Shuttle', Report of the Presidential Commission on the Space Shuttle Challenger Accident, Vol. 2, Appendix F, *in fine*.

integrating them requires 'technical juristic sophistication as well as a knowledge of general epistemology.'[2]
Attempts to regulate long-term sustainability of space activities in general, and active debris removal, space debris, or space object interactions in particular, are no exception insofar as they speak to an ability effectively and legitimately to apportion physical presence of numerous (international) legal subjects in, and thus mediate rivalrous use of, a limited volume of orbital space through sophisticated techniques of managing (future growth of) a space object population. The underlying 'factual' premise being that two distinct objects cannot (tend to) simultaneously occupy an identical orbital position without thereby risking to incur consequences antithetical to sustainability or safety, such as generating hazardous debris fragments or variously intensive and supportable instances of potentially harmful physical interference.

2.1. Centrality of Prevention and Risk

Space debris mitigation, active debris removal, collision avoidance, prevention of potentially harmful (physical) interference, and space traffic management, while distinct, essentially all seek somehow to manage or administer the (growth of the) orbital object population through *preventing collisions* or *(potential) physical interference* between manmade 'objects' launched into outer space, and fragments thereof, including launch vehicles, i.e. 'space objects'. Minimally, they share common goals of (a) maintaining navigational orbital safety by preventing collisions, and consequent proliferation, of space objects – most of which are non-functional and no longer useful, i.e. space debris – and (b) ensuring operation and safety of functional satellites by preventing 'a reduction in operational capacity due to debris impact'[3] or other types of collisions. In sum, the common objective is *preventing collisions between manmade objects in orbit*.
A growing body of scientific, technical and institutional literature examines *factual behavior* and *physical interrelations* of such objects. It describes and categorizes *risks of collision or interference* attending objects or classes of objects either in relation to each other or to more general sustainability objectives. Observational data of the material orbital environment underlie various models, risk projections and consequent prognoses and recommendations for sustainability and (management of) the space object population to as confident a degree as observation, modelling and trajectory propagation allow for various projected time periods and orbital regions.

2 A. Peczenik, Scientia Juris: Legal Doctrine as Knowledge of Law and as a Source of Law (Volume 4), in: E. Patiaro (Ed.), A Treatise of Legal Philosophy and General Jurisprudence, Springer, Dordrecht, Berlin, Heidelberg, New York, 2005, pp. 28-29.
3 See, e.g., C. Bonnal and D. McKnight (Eds.), IAA Situation Report on Space Debris - 2016, International Academy of Astronautics (IAA), May 2017, pp. 125-137.

2.2. Structural Contours of Circumterrestrial Space Law

On that basis, this paper posits the following. *If*, so as to maintain general sustainability and safety, prevent particular instances of physical interference, and avoid collisional debris proliferation, it is found to be desirable to effectively operationalize (international space) law so as to describe, qualify, mediate, steer, limit, manage or otherwise legally modulate conduct in respect of physical space object interactions and, thus, between any implicated (international) legal subjects, *then* (international space) law will be required to take functional account of (f)actual space object behaviors and the consequent dynamic orbital web of interactional risks – as described in mostly quantitative terms of orbital parameters, risk projections, and object population trends. *Ex facto sequitur lex*.

Literature so far does not sufficiently elaborate the logical consequences of the above proposition. While technological, political and institutional developments obfuscate the line between the *lex lata* and *lex ferenda* applicable to activities and objects in Earth's orbits, a way forward for space law scholarship might lie in a *structural analysis of the mutual relations between space objects*. Broadly, the analysis entails mutual deconstruction and integration of both the scientific methodologies and ontologies for observing, studying and describing the physical reality of material space object relations – *scientific or physical facts* – as well as the methodologies, ontologies and more typically hermeneutical activity of (international) law encompassing those material relations in order to confer attendant rights or obligations on implicated legal subjects – *social or legal facts*.

The 'structural analysis' turns on contrasting mutual relations of space objects *de facto* with mutual relations *de iure* through mapping, overlaying and contrasting these two broad schemas of relational structures to ascertain what insights might be gleaned therefrom. It may cast light on present structural dimensions – *lex lata* – but also identify structural contours of the interwoven and partly mechanical lattice, constituted by both the aggregated material configuration of manmade orbital objects as well as their particularized relations, upon which to construct effective and legitimate regulation of orbital activities – *lex ferenda*. Moreover, structural clarity can contribute in appraising and evaluating politico-legal developments as well as to direct limited geopolitical negotiatory capital toward more useful and effective regulation.

3. Mutual Relations of Space Objects: *De Facto* and *De Iure*

The 1979 information paper entitled 'Mutual Relations of Space Missions' was an early document introducing collision prevention to COPUOS. Largely devoted to hazards of space object collisions, it emphasizes avoidance of conjunctions and debris proliferation for preserving a sustainable, safe and

navigable Earth orbital environment, concluding it '… is just a question of taking into consideration, … all possible relations with other space objects which might be encountered by [a] particular space mission during its active as well as inactive lifetime.'[4]

However, the material orbital environment exhibits numerous (potential) mutual relations between manmade objects in complex mechanical and temporal geometries. In principle, (international space) law legally qualifies and connects each of those objects in some way to sovereign States, international organizations, or such other legal subjects as may be relevant for purposes of registration, attribution, jurisdiction and control, authorization and supervision, responsibility and liability, or for more generally determining normative or social attributes of space objects. The space lawyer hence faces a kaleidoscopic legal task: to project upon the *physical configuration and processes* of such *de facto* mutual relations a *normative matrix* of *de iure* relevant socio-economic, political and legal facts basically spanning any given legal subjects - including operators, polities, sovereign entities, beneficiaries, aggrieved parties – as well as applicable rights, obligations and jurisdictions connected to space objects under scrutiny and at risk of encounter.

3.1. De Facto: Conditional Risk Environment and Structural Indivisibility

Numerous endogenous and exogenous factors impact the risk adhering to any given object.[5] Endogenous factors include attributes of the scrutinized object such as cross-section, volume or mass. A poignant example are studies focusing on particularly massive and thus risk-generating objects as worthwhile targets for active debris removal (ADR) due to efficient rates of return in orbital environmental preservation and debris prevention.[6] Moreover, in line with the 1979 COPUOS document, scientific literature increasingly suggests to *dynamically* account for variations in orbital conditions. An holistic account both of extant objects and of planned future space missions appears preferable in order to (more) accurately delineate those physical activities, in terms of interference probabilities and

4 COPUOS, Mutual relations of space missions - Information paper prepared by the secretariat, *UN*. Doc. A/AC.105/261, 7 December 1979, para. 20.

5 For a discussion of some of the salient legal ramifications of such a risk-based paradigm, see: W. Munters, Active Debris Removal, International Environmental Law, and the Collective Management of Risk: Foundations of an International System for Space Traffic Management, in: A. Froehlich (Ed.), Space Security and Legal Aspects of Active Debris Removal (Studies in Space Policy; European Space Policy Institute), Springer Nature, Switzerland, 2019, pp. 131-154.

6 D. McKnight, M. Matney, K. Walbert et al., Preliminary Analysis of Two Years of the Massive Collision Monitoring Activity, IAC-17-A6.2,1,x35961, 68th *International Astronautical Congress* (IAC), Adelaide, Australia, 25 – 29 September 2017.

environmentally tolerable risks, which a fluctuating object environment may accommodate at any given time.[7] Indeed, a disintegrating space object produces fragments that over time disperse into a sphere enveloping Earth.[8] A collision or fragmentation spawning debris can appreciably alter exogenous collision risks for others, thereby potentially impairing third-parties' technical ability or enjoyment of the right, as belongs to 'all States' pursuant to Article I of the Outer Space Treaty of 1967 (OST), to traverse orbital space. Due to orbital mechanics, operational conditions in Earth orbital space may thus be subject to relatively rapid and dynamic anthropogenic change. Acts, or omissions to act, concerning a single space object may impose (potential) material effects on others within affected orbital regime(s) over various timescales. This interwoven mutuality or degree of physical coupling between orbital objects and activities is here termed the *structural indivisibility* in mutual relations of space objects.

Indeed, various designs and studies of large constellations in low Earth orbit (LEO) evince concern to decouple mutual physical relations of constellation objects so as to reduce the structural indivisibility between them, indicating emerging practice in that respect by envisaging management of intra-constellation risks through actively removing unresponsive satellites, automated or autonomous collision avoidance or, pertinently, by distributing constellation members in staggered orbital shells separated by some relevant altitude and/or inclination. However, constellations may also be impacted by exogenous events and decisions that lie beyond control of the operator or jurisdiction(s) of the authorizing and supervising State(s). A recent study employs the term 'conditional collision probability', i.e. 'the probability that a collision occurs due to a satellite of the constellation provided that another independent collision has occurred at a given date.'[9] A hypothetical catastrophic collision otherwise independent of the constellation is modelled – not unlike the 2009 *Iridium-33* and *Kosmos-2251* collision – to produce some 3000 debris fragments larger than 10cm. During the hypothesized 10-year post-mission disposal phase for end-of-life constellation members in LEO, incapable of avoidance maneuvers, collision risk is conditional such that

7 See, e.g., F. Letizia, S. Lemmens, B. Bastida Virgili and H. Krag, Application of a debris index for global evaluation of mitigation strategies, 161 *Acta Astronautica* (2019) 348 et seq.

8 See, e.g., the fragmentation cloud generated by the explosion of an Ariane-1 H-10 upper stage, as described and depicted in H. Klinkrad, Space Debris: Models and Risk Analysis, Springer-Praxis, Berlin, Heidelberg, New York, 2006, p. 72.

9 R. Lucken and D. Giolito, Collision risk prediction for constellation operators, 161 *Acta Astronautica* (2019) (492), 498.

> '[e]ven though the collision considered [in the study] took place 400km away from the constellation operational altitude, the influence on the collision risk for de-orbiting satellites is significant. In 2065, 40 years after the hypothetical fragmentation, the collision risk is as high as 15%, … By 2035, the collision risk reaches 2% in case of a catastrophic collision, as opposed to only 1.2% in the averaged reference scenario.'[10]

3.2. De Facto: Material Environment

As the above demonstrates, physical behavior and mutual relations of space objects are described by a *scientific and technical language of risk*. Risk determinations form the 'factual' substrate for a legal framework desirous of effectively regulating space object relations or preventing physical interference. Legally conceiving of such an enmeshed physical state of affairs suggests that the precise substance, correlation, disposition, enjoyment or frustration of many, if not all, rights and obligations - imputable to (international) legal subjects attending a space object's presence in orbit - will be likewise 'conditioned' by the material conduct of other actors dynamically influencing the object population.

To aid in terminological clarity and promote study of linkages between scientific-quantitative descriptions of space object relations on one hand, and the socio-political and legal view of them on the other, it is proposed to term the 'factual', empirical-scientific, description of the web of relations constituted by *manmade* objects the *material environment* of Earth orbital space - as distinct from the natural environment which includes also natural factors such as fluctuating atmospheric volume or density, micrometeoroids, solar cycles and other space weather phenomena. The *material environment* denotes the aggregate orbital configuration of corporeal, physical manmade objects, the attendant interstitial risks and the particular potential or actual interaction between space objects, as described in largely quantitative terms – the relevant 'facts'.

3.3. De Iure: Social Milieu and Variable Normative Matrix

Opposite the above concept of the *material environment*, it is suggested to introduce into the literature the concept of the orbital '*social milieu*'. The social milieu is multifaceted and encompasses the politico-legal elements consisting of the specific bundles of variable subjective legal attributes – such as mutual entitlements, rights or duties – that on the basis of applicable (international) law may attend each particular object and its interactions, whether in isolation, bilaterally, multilaterally or collectively. Both concepts largely mirror a traditional distinction between empirical facts and sociological/moral/legal facts, distinguishing between a largely quantitative view of numerous physical space objects on the one hand and their particular

10 Ibid.

qualitative and normative attributes on the other. The first tends toward the *objective* or empirical structure of material space object relations, the second toward the actual or potential subjective legal or normative relationships instigated thereby. The distinction may promote more rigorous examination and categorization of various structural regulatory or social dimensions of physical limits to use of orbital space.

Arguably, the freedom enshrined in Article I OST for all States to access, explore and use outer space is the international legal principle underlying the conception of orbital object interactions as a social phenomenon, especially when supported by the principle of due regard and the obligation to undertake appropriate international consultations in case of potential harmful interference in Article IX OST. Articles I and IX provide the predominant international norms which countenance potential physical interference between objects as a normatively infused social fact. In that sense they provide the normative bridge between the material environment and the social milieu as concerns prevention.

Space objects are *res corporale* and represent the predominant material – in the sense of having mass – instrumentalities by which States or other spacefaring entities explore, make use of, derive benefits from, and carve an exclusionary path through, the shared and limited spatiotemporal reservoir of Earth orbits. Vagueness surrounds the 'socially' applicable *lex lata* for accountability, responsibility, liability or other putative rights and obligations of States in connection with space objects. Multiple space treaty provisions or precepts of general international law nonetheless prescribe 'connecting factors' linking space objects to particular States-subjects, or organizations of States-subjects, for purposes of registration, attribution, exclusive jurisdiction and control, responsibility, authorization and supervision, liability, return, due regard, potentially harmful interference, and so on.[11] Theoretically, every space object or activity therefore is always already imbued with – sometimes latent, sometimes actual – *subjective jural attributes* that render it legally apprehensible. Every single manmade object thus comprises a discrete bundle of – sometimes certain, at other times mostly putative, inchoate or yet unrealized – normative attributes expressive of those particular legal interests, rights and responsibilities as may be understood to attach to that space object(s) and connected legal subjects. In aiming to prevent collisions, the precise scope, contours and substance of *each* discrete bundle must, as a matter of logical necessity and legal process, be determined and delineated with respect to such bundles as attach to other objects at risk of mutual interference.

11 B. Cheng, 'Space Objects and their Various Connecting Factors', in: G. Lafferanderie and D. Crowther (Eds.), Outlook on Space Law over the Next 30 Years – Essays Published for the 30th Anniversary of the Outer Space Treaty, Kluwer Law International, The Hague, Boston, 1997, p. 203 et seq.

When launching or otherwise introducing a material object or fragments thereof into orbital space and thereby instigating risk of physical interference, a (legal) subject thus inexorably enters into an evolving, multidimensional legal – social – relationship. It appears inappropriate therefore to overly reify a space object by perceiving it merely as a material object or non-attributable 'environmental' factor in the sense of such objects being somehow wholly subsumed by the non-subjective, non-social material environment. Technically, this desocialization would seem to arise in the first instance due to technical barriers to observation and tracking that preclude sufficient evidence to definitively link an object to (conduct of) a particular actor - e.g., attribution or imputation. Normatively, desocialization seems largely a function of interdependent issues of reticence to accept clear limits to use of orbital space and of difficulty in normatively qualifying a space object. Tentatively, one can expect the material environment to grow progressively more integrated with the 'social milieu' as tracking capabilities grow increasingly sophisticated or widespread and the perceived need increases for articulated measures to preserve sustainability and prevent collisions.

4. Integration of Physical Environment and Social Milieu: the Common Construction of Risk

4.1. Risk in International Law: retrospectivity and bilateralism

Prevention has gained prominence in various domains of international law, practice and adjudication under influence of growing awareness that in some spheres of human activity prevention is preferable because of the limited utility of retrospective legal logic when faced with a physical impossibility to restore the *status quo ante*. Prevention of collisions producing irremediable space debris or space object proliferation exemplifies such concerns. 'The topic of prevention' has been characterized by the International Law Commission as '… concerned with the management of risk.'[12] However, this apparent shift toward management of future events so far accords rather uneasily with the traditional legal paradigm of translating present and past events into legal concepts on the basis of evidence. 'With the advent of risk rationality,' it is noted, 'this evidence does not derive from the past, but the rationalization of a possible future… in this context, legal cases operate on the pre-mediation of possible futures with the consequence that the legal

12 Third Report on international liability for injurious consequences arising out of acts not prohibited by international law (prevention of transboundary damage from hazardous activities), by Special Rapporteur Pemmaraju Sreenivasa Rao, *UN*. Doc. A/CN.4/501, *YBILC* 2000, Vol. II, Part One, p. 121, para 27.

questions of aim and intent are replaced by a focus on the potential harmfulness of allegedly attempted conduct.'[13]

An evolving body of international case law concerning environmental matters and prevention of transboundary harm demonstrates the intrinsic connection between prevention and risk management. Following a line of well-known cases, and not entirely unlike the provision in Article IX OST, the International Court of Justice now recognizes a general obligation to undertake prior environmental impact assessments (EIAs) when activities in or under supervision of a State may harm other States or areas beyond its national jurisdiction and control (e.g., outer space) and to pursue prior notification and consultation with affected States in presence of an appreciable risk. Although general legal articulation of risk rationality remains elusive, (international) law contains many examples of instruments with risk-based mechanisms that within their scope operate on the relevant social milieu to delineate mutual legal entitlements and duties regarding particular types of activities, acts, omissions to act, or potential consequences thereof.

Such mechanisms generally function either to *permit* or to *restrict* particular (future) conduct in some manner through (1) prescribing a procedure and/or allocating responsibility for ascertaining risks prior to qualified activities, (2) enumerating normative permissive or restrictive risk thresholds or imposing an obligation to do so, and (3) prescribing how and by who the determined material risk is to be weighed against the normative thresholds. TOWNLEY, directly inspiring the title of the present paper, offers a recent and comprehensive overview of the rise of risk management in international law. He highlights that risk assessment, which he defines as '… a static principle with dynamic output based on probabilities', may be helpful in policymaking or in calibrating proper legal responses to situations subject to rapid change where traditional treaty-making is a less than ideal fit,[14] such as operational safety and sustainability in orbit.

Risk assessment may also fulfil a retrospective function. Indeed, it is not entirely inconceivable that some future judicial case regarding liability would, for example, establish 'fault' for damage caused by and to space objects on the basis of finding some perceived restrictive normative risk threshold had been exceeded. However, because space activities are 'ultrahazardous', an appreciable risk is to be borne by whoever opts to make use of orbital space. The recognition that, by introducing into orbit a space object, an actor enters willfully into a hazardous situation motivated inclusion of a fault-based

13 F. dos Reis and O. Kessler, 'Constructivism and the Politics of International Law', in: A. Orford and F. Hoffmann (Eds.), The Oxford Handbook of the Theory of International Law, Oxford University Press, Oxford, 2016, p. 363.

14 S. Townley, The Rise of Risk in International Law, 18(2) *Chicago J. Int'l L.* (2018) 594, pp. 638-639.

regime in the 1972 Liability Convention. That logic conceives of orbital interactions as essentially bilateralized legal relationships that are judged exclusively in retrospect and which for legal purposes are instantiated *ut singuli* through the lens of singular objects and between particular pairs of objects. These potential relationships manifest *ad hoc* on the basis of particular 'harm' to particular actors, thereby failing to account for collective processes of growth in spatial density or collective dimensions of preventing physical interference. To the extent that traditional bilateral logic underlies international space law, then, it fails to appropriately incorporate risk rationality by way of which, for example, 'third-parties' become part of a continuous chain of potential interference by virtue of the risk imposed on them by the outcomes of innumerable external bilateral relationships as well as their interest in minimizing that risk.

4.2. A Static Risk Principle with Dynamic Outcomes in Orbital Space

Finally, a brief examination is in order of the existence, degree, substance and disposition of normative-legal restrictions or permissions circumscribing action or inaction in respect of space objects and potential physical interference. To determine and apply current, or elaborate future, regulation regarding mutual object relations from a bilateral perspective presupposes identifying, interpreting, attributing, qualifying, appropriately weighing and attempting to mediate, resolve or dispose of the interwoven legal relations that obtain in interactions between objects normatively imbued by distinct but correlated bundles of subjective legal attributes, interests, competences, rights and responsibilities – to say nothing of cultural, political, ideological or socio-economic differences. Doing so ideally against a normative horizon constituted by the common goal of preserving sustainability and preventing collisions. Legally mediating material space object relations then involves applying a *subjectively* (i.e. connected legal subjects) and *dynamically* (i.e. evolving orbital material conditions) *variable matrix* of bundled procedural and substantive norms. Insofar as the material environment is conditioned by behavior of other or third parties, the respective bundles of jural attributes of mutually related objects will in effect be relatively 'conditional'.

This paper therefore posits the existence and gradual emergence of a 'static' risk principle with 'dynamic' outcomes. Articulation of the principle may offer effective means to both accommodate the identified material 'structural indivisibility' and interwoven conditionality or interdependence, and to bridge the gap with the social milieu of legal concepts, rights, obligations and mechanisms regarding limits to physical use of orbital space. On one hand, the principle is materially 'static' due to the interdependence orbital mechanics introduces among actors and objects capable of mutual interference. It is normatively static on the basis of collisions being either generally undesirable, if not yet unlawful, from a sustainability perspective.

On the other hand, the outcomes of the principle when applied to the material environment at any given time are 'dynamic': the principle's regulatory output normatively captures the myriad (natural and) anthropogenic variations in orbital conditions.

4.3. Toward Legal Mediation of Mutual Space Object Relations: Mapping Structural Contours

Sustainability or collision prevention are fundamentally premised on some minimal *physical* ordering of space objects. A legal system desirous of facilitating that physical order (i.e. through dictating physical object behavior or managing spatial densities) requires procedural and substantive machinery to produce variable norms that effectively translate a given requisite physical order to a normative ordering of social relations divided into categories of desirable or undesirable conduct (i.e. law) on the basis of collisional risk or potential created thereby. A principle of risk, understood to encompass the *normatively constructed* risk thresholds that operate to permit or restrict said conduct, therefore appears as a central *structuring principle* in a system of law seeking to order mutual relations in orbital space.

Mapping foundational *legal or jural structures* of international law onto the *structure of physical relations* of space objects is an illuminating heuristic device to investigate how interwoven legal relationships between space objects are structured. It is appropriate to conceive of the bundle of jural attributes imbuing discrete space objects as a variable matrix of *Hohfeldian jural correlatives* whose existence and precise qualification and substance will depend on the outcome of the risk principle when applied to protean material circumstances. Indeed, the table below contains the Hohfeld jural correlatives 'that *structure* the internal relationships among the different legal rights' of subjects in a given situation.[15]

Table 1. *Hohfeldian* Jural Correlatives

Right	Privilege	Power	Immunity
Duty	No-right	Liability	Disability

In a legal relationship between legal subjects the 'right' of one subject correlates to a 'duty' for the other not to unduly frustrate or impede enjoyment of that right. A 'privilege' of one subject correlates to 'no-right' for

15 J.W. Singer, The Legal Rights Debate In Analytical Jurisprudence From Bentham to Hohfeld, *Wisconsin L. Rev*. (1982), p. 986 (emphasis added). See also W.N. Hohfeld, Some Fundamental Legal Conceptions as Applied in Judicial Reasoning, 23 *Yale L. J.* 16 (1913), p. 30.

others within the scope of that privilege, and so on. The Hohfeldian jural correlatives attending a particular manmade object and their particularized qualification and substance vary according to the dynamic normative output of the risk principle as applied to the interactions between objects and actors imposing mutual collision risk in some way.

For a given category in the matrix, qualification (e.g., a 'duty' entailing either an obligation of result or of conduct) and actual substance (e.g., to maintain a particular trajectory, to apply particular delta-v, to utilize a particular PMD-period or disposal route) varies according to normative evaluation of protean material risk and the consequent permissiveness (i.e. right, privilege, power, immunity) and/or correlated restrictiveness (duty, no-right, liability, disability) held to be applicable to a particular space object *in correlation to* another object at some moment or period in time.

Let us hypothesize, at a micro level, that an object, A, risks colliding with object B and the desired regulatory outcome is one of preventing these two objects from colliding. A legal relationship between A and B manifests. Exceedance of some normatively determined collision risk threshold triggers either permissive or restrictive prescription(s). Object A is now attended by either a permissive 'right' (or privilege, power, immunity) to maintain its course or a restrictive 'duty' (or no-right, liability, disability, respectively) to cede its trajectory, which obtain specific substance according to contingent material facts of the situation, such as operational conditions, safe maneuver parameters, delta-v requirements, technical spacecraft and operator capabilities, functional status, and so on. Object B exhibits the relevant jural correlative similarly contingent in substance.

At macro level, the situation is much more complex and unnuanced two-dimensional application of correlatives tends to overly bilateralize legal relationships by focusing solely on interaction between any two space objects while de-emphasizing the web of aggregate orbital relations. In reality, the situation, and thus the applicable normative matrix, is multipolar and thus decidedly multidimensional: distinct configurations of rights and duties overlappingly imbue any number of manmade objects in correlation to any variety of others. For instance, two correlated objects may both be simultaneously encumbered by some measure of duty or liability to one another, to third parties, or both.

However, present international (space) law operates largely on the basis of bilateral relationships between individual interests, rights and obligations and apart from rather broad principles offers little guidance or indication as to the proper normative thresholds in applying, for example, Article I or Article XI OST to apportion material presence among actors in orbital space, if any. To make legal sense of mutual relations in orbital space under the premise of collision prevention, such a matrix must therefore be reiteratively applied and projected *ad hoc* upon *each* potential relationship established between legal

subjects through *all* manmade objects in orbit. Indeed, a similar 'necessity of individual statements for very large numbers of small objects' is more or less why PEREK was hesitant in his eventual acceptance that space debris legally constitute space objects. An acceptance he qualified, on the basis of daunting technical or practical complexity in determining the discrete legal attributes for inordinate numbers of manmade objects, with the corollary necessity of developing tailored norms to classify objects or groups of objects so as to regulate them according to size, mass[16] or, as posited here, collision risk.
Nonetheless, correlatives form jurisprudential foundations for the present structure of international law and offer an appropriate heuristic to conceptualize, operationalize, socialize and ultimately 'legalize' mutual relations between space objects from the perspective of collision prevention. Even if the heuristic advantage may just be to demonstrate the profoundly complex multilateral and collective dimensions of effectively regulating material activity in orbital space.

5. Conclusion

International production of legal norms envisaged to enact management and administration of mutual physical relations between space objects in Earth orbit would essentially amount to the common construction of a central and static risk principle encapsulating, at a minimum, those *common procedures* which, according to dynamic changes in the material environment, adaptively order the social milieu by generating the discrete bundles of *dynamically evolving* substantive rights and correlative duties attending each manmade object in orbital space at any given moment in time.

16 See L. Perek, Definition of Space Debris, 44 *Proc. On L Outer Space* (2001) 289.