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# Compartmentalization of Activities in Nuclear Bodies and The Pentagon

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# Compartmentalization of Activities in Nuclear Bodies and The Pentagon

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## Rule to Build By

"To conduct multiple activities simultaneously, subdivide spaces and assign different functions to each space." (Morris, Lane, 2020)

## What

Compartmentalization of functions and equipment of those functions allows for efficiency of processes. Nuclear bodies and the United States' Pentagon share the compartmentalization of functions within a larger space that is still accessible to all members of the processes.

## How

Nuclear bodies are non-membraned sub-organelles within the nucleus that contain the proteins and components to perform a nuclear activity, displayed in Figure 1. There are several types of nuclear bodies, all of which perform a different function. While they are self-contained, they can move throughout the nucleus, traveling among the chromosome territories that contain individual chromosomes. Nuclear bodies compartmentalize nuclear activities so that each performs a different function that allows for efficiency within the nucleus (Mao, Zhang, & Spector, 2011). Nuclear bodies are able to separate from the nucleoplasm by concentration-dependent phase-separation. This results in high macromolecular concentration. This environment allows for enhanced and faster reactions, making the activities performed by nuclear bodies much more efficient than if it were to be performed in the nucleoplasm (Sawyer, Sturgill, Sung, Hager, & Dundr, 2016).

Cajal bodies is the largest group of nuclear bodies and are multifunctional, displayed in Figure 2. Cajal bodies primarily control the production of snRNPs though also contain the components required for transcriptional activation, assembly of several RNPs, RNA processing, and telomerase assembly (Mao et al., 2011; Sawyer et al., 2016). The defining components within a Cajal body are proteins called coilin and survival motor neuron (SMN) (Mao et al., 2011). The SMN protein is the vital component for the synthesis of snRNPs, which when assembled with pre-mRNA and other proteins make the spliceosome (Hebert, Szymczyk, Shpargel, & Gregory Matera, 2001). Coilin on the other hand functions to provide structure to Cajal bodies as well as other nuclear bodies (Shaw et al., 2014).

Nucleolus is the largest nuclear body within the nucleus, displayed in Figure 3. Its main function is the synthesis of rRNA and ribosomal subunits assembly (Kalinina, Makarova, Makhotenko, Love, & Taliansky, 2018). The defining component contained within the nucleolus that gives it its specific function is the RNA polymerase I machinery (Mao et al., 2011). Due its important and highly regulated function, alterations in the process can affect the nuclear organization. These process alterations affect the coilin in the nucleolus, which affect the structure and distribution of the nucleolus and also discontinue the release of ribosomal proteins into the nucleoplasm (Boulon, Westman, Hutten, Boisvert, & Lamond, 2010).

Nuclear speckles, displayed in Figure 4, are the most numerous of the nuclear bodies, with each nucleus containing approximately 25-50 nuclear speckles (Mao et al., 2011). Its main function is as a storage site for splicing factors as well as modification (Spector & Lamond, 2011). The defining proteins and components within the nuclear speckle are SRSF2, SRSF1, and Malat1 (Mao et al., 2011). SRSF1 and SRSF2 both work within the nuclear speckle to regulate the assembly of pre-mRNA processing factors (Tripathi et al., 2012). Malat1's role is primarily to regulate and influence alternate mRNA splicing via phosphorylation (Galganski, Urbanek, & Krzyzosiak, 2017). Due to the fact that alternative splicing is a large producer of genetic diversity, the function that nuclear speckles play within the nucleus is central to the efficient functioning of the nucleus and the cell itself (Spector & Lamond, 2011).

Obviously, nuclear bodies play large and varied functions within the nucleus, each specializing in a necessary nuclear activity. The genome itself that these and other nuclear bodies act upon is organized via chromosomes into defined chromosome territories. These chromosome territories are organized throughout the nucleus based on the frequency with which a nuclear body needs access to the chromosome. Chromosomes with constitutive gene-rich regions are oriented towards the center of the nucleus. Chromosomes with low densities of gene-coding regions are oriented to the edge of the nucleus (Cremer & Cremer, 2010). The nucleolus stays fairly stationary, situated towards the center of the nucleus, but other nuclear bodies, such as Cajal bodies, move throughout the nucleus, providing them access to various portions of the genome (Misteli, 2005). The compartmentalization of proteins necessary for different nuclear activities into nuclear bodies allow for efficiency and control of the processes.

The Pentagon in Arlington, VA is the United States' Department of Defense headquarters, displayed in Figure 5. What makes the structure of the Pentagon unique and efficient is its complex compartmentalization. In addition to the five sides that gives the building its name, there are also 5 rings that comprise the building. The offices and armed forces within the Department of Defense are separated by "wedge", the side of the building, and the ring in which it is housed (Grymes, n.d.). Each office performs a different function for the Department of Defense. Despite being one of the largest office buildings in the world, holding 40,000 people, communication is made easy by the design of the Pentagon that allows a person to travel from one point to the farthest point in the building within 7 minutes (Grymes, n.d.). Having the offices in defined areas allows for efficient day to day work, while the easily navigable building allows for easy communication in times of crisis or collaborative work.

# Why

There are a multitude of different nuclear bodies that perform vital nuclear activities. This compartmentalization of functions and their required proteins have several advantages that have led to their evolution across several species (Dundr, 2012). As previously mentioned, the membrane-less nuclear bodies are created by concentration-dependent phase-separation and this creates a concentration of macromolecules within a space (Sawyer et al., 2016). This molecular crowding then forces water out of the space, which lowers the entropic threshold for reactions

(Sawyer & Dundr, 2018). Through this process, biochemical assembly reactions occur faster and proteins reach their final folded shape at an increase rate (Dupuis, Holmstrom, & Nesbitt, 2014). In addition, the nonrandom location of chromosomes within chromosomes allows for nuclear bodies to be located at specific gene-loci so that the nuclear bodies are located where they are most utilized (Dundr & Misteli, 2010). This mobile compartmentalization of nuclear activities allows for efficient and adaptable processes.

Aside from the efficiency of reactions that results from the use of nuclear bodies, benefits also arise from the sequestering of specific proteins into a singular space. Some proteins or non-RNAs are transcribed at a much less frequency than other constitutive transcripts, although just as necessary for various reactions or nuclear functions. By sequestering such proteins or non-coding RNAs into a single or few nuclear bodies, their use and location is controlled. For example, there are approximately only 1,000 or less copies of U7 snRNP in a mammalian cell. Despite its small copy number, it plays a major role in processing the 3' end of histone mRNAs (Marz, Mosig, Stadler, & Stadler, 2007). Because of its important function and small copy number, the U7 snRNPs are sequestered in a nuclear body called the Histone Locus Body (HLB) and without such sequestering, the volume of U7 snRNPs throughout the nucleus would be insufficient to perform the necessary processes (Tatomer et al., 2016). There are numerous other examples of proteins and non-coding RNAs that would not function as well or at all without the compartmentalization with nuclear bodies. This compartmentalization phenomenon ensures the correct functioning of cellular processes throughout the whole cell.

The Pentagon was originally planned and constructed to be the United States' military center when World War II began in Europe. The expected expanded military forces required as well as the strategic planning that would need to occur prompted the idea for a single building that held members of the Department of Defense and all of the armed forces. During crises and wartime, communication was essential, making easy access to all areas of the building essential. However, during peace time, each office and department are separated so that all tasks can be carried out efficiently (Grymes, n.d.).

# Figures

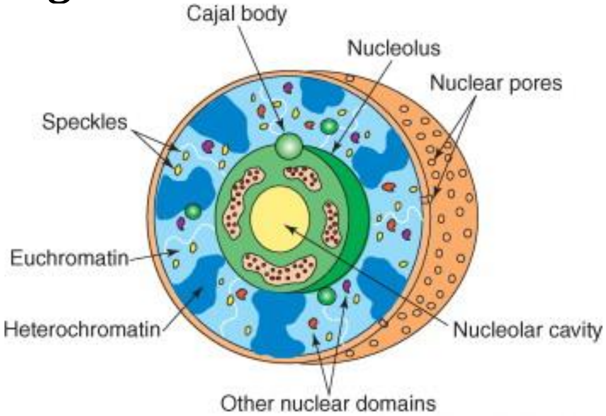


Figure 1. Diagram of Nucleus. Nuclear bodies, including nuclear speckles, the Cajal body, and nucleolus are shown in proportion to their approximate numbers and location within a nucleus. Euchromatin, heterochromatin, and nuclear pores are also included in the schematic drawing. Image obtained from Shaw and Brown, 2004.

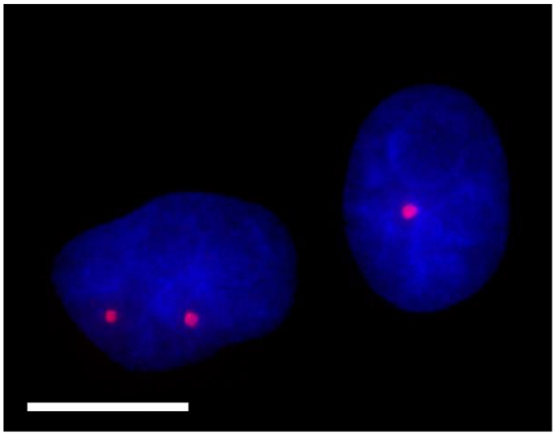

Figure 2. Cajal Body Visual. Cajal bodies within a HeLa cell visualized with indirect immunofluorescence. White scale bar 10 µm. Image obtained from Blazikova, Malinova, Novotney, 2016.

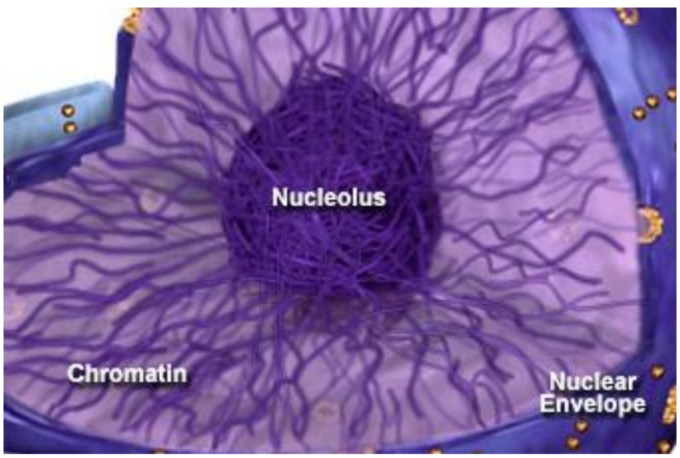


Figure 3. Nucleolus Visual. The nucleolus is situated in the center of the nucleus, surrounded by chromatin. Image obtained from M. Davidson, 2015.

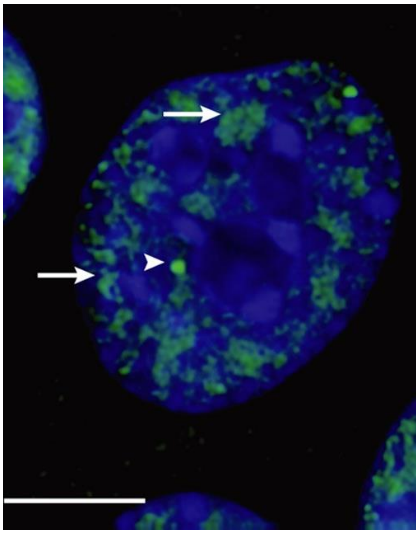

Figure 4. Nuclear Speckles Visual. Nuclear speckles in a HeLa cell labeled green with a Y12 antibody and marked with an arrow. Arrowhead marks a Cajal body. Scale bar is 10 µm. Image obtained from Lamond and Spector, 2003.

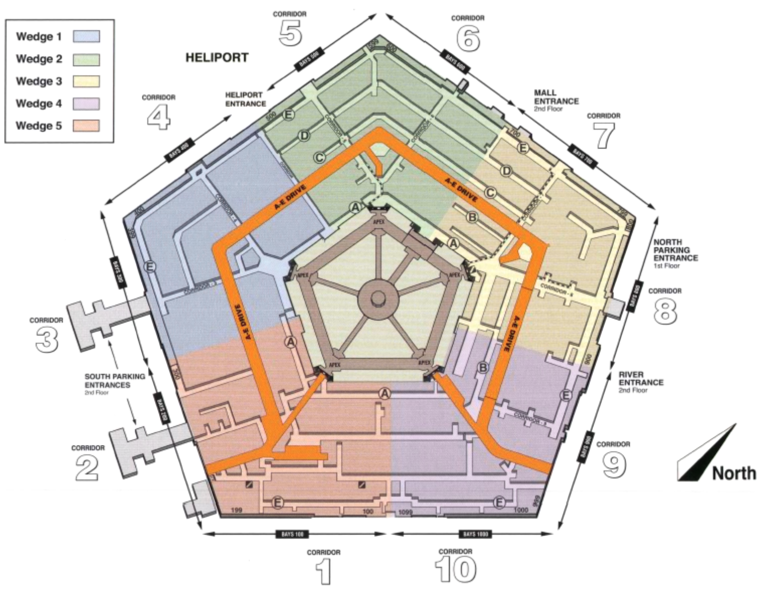


Figure 5. Diagram of The Pentagon. This figure displays the internal structure of the United States Pentagon. The wedges that typically separate departments are color-coded via the key in the figure, Wedges 1-5. The 5 internal rings are labeled A-E, with A being the most internal ring and E being the most external ring. The numbered corridors displayed around the outside of the Pentagon represent the beginnings of the hallways from the outermost entrances. The labeled black boxes accompanied by arrows along the edges of the Pentagon name the street that are adjacent to that side of the Pentagon. The orange line that runs through the Pentagon and labeled A-E drive is the most efficient way to access all five rings of the Pentagon. Image from Goldber, Papadopolous, Putney, Berlage, & Welch, 2007.

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