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Recursively Arbitrarily Vertex-Decomposable Suns*

Olivier Baudon^a, Frédéric Gilbert^a, Mariusz Woźniak^{b†}

^aLaBRI, Université de Bordeaux

351, cours de la Libération, 33405 Talence Cedex, France

^bFaculty of Applied Mathematics, AGH University of Science and Technology
Al. Mickiewicza 30, 30-059 Kraków, Poland

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Abstract

A graph $G = (V, E)$ is arbitrarily vertex decomposable if for any sequence τ of positive integers adding up to $|V|$, there is a sequence of vertex-disjoint subsets of V whose orders are given by τ , and which induce connected graphs. The aim of this paper is to study the recursive version of this problem on a special class of graphs called suns. This report is a complement of [BGW10]

1 Terminology and preliminary results

In this paper, we deal only with simple graphs, that means graphs without loops or multiple edges. We denote by n the number of vertices, also called *order* of the graph and by m the number of edges. If $G = (V, E)$ and $A \subseteq V$, $G[A]$ will denote the subgraph of G induced by A . For more definitions on graphs, please refer to [Die05]

1.1 Arbitrarily Vertex-Decomposable Graphs

Let n, τ_1, \dots, τ_k be positive integers such that $\tau_1 + \dots + \tau_k = n$. $\tau = (\tau_1, \dots, \tau_k)$ is called a *decomposition* of n . If the size of the decomposition is pertinent, we would precise *k-decomposition*.

Let $G = (V, E)$ be a graph of order n , and τ a k -decomposition of n . G is τ -*Vertex-Decomposable* iff it exists a partition of $V : V_1, \dots, V_k$ such that for each $i, 1 \leq i \leq k$

- $|V_i| = \tau_i$
- $G[V_i]$ is connected

A graph $G = (V, E)$ of order n is *Arbitrarily Vertex-Decomposable* (in short *AVD*) iff for each decomposition τ of n , G is τ -Vertex-Decomposable.

1.2 Recursively Arbitrarily Vertex-Decomposable Graphs

Definition 1 A graph $G = (V, E)$ with order n is *Recursively Arbitrarily Vertex-Decomposable* (in short *R-AVD*) iff

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‡email addresses: {olivier.baudon, frederic.gilbert}@labri.fr, mwozniak@agh.edu.pl

- $G = K_1$
or
- G is connected and for each decomposition $\tau = (\tau_1, \dots, \tau_k)$ of n , $k \geq 2$, it exists a partition of $V : V_1, \dots, V_k$ such that for all $i, 1 \leq i \leq k$
 - $|V_i| = \tau_i$
 - $G[V_i]$ is R-AVD

Remark 2 A graph $G = (V, E)$ of order n is R-AVD iff for each integer $1 \leq \lambda \leq \lfloor \frac{n}{2} \rfloor$, it exists a subset V_λ of V such that

- $|V_\lambda| = \lambda$
- $G[V_\lambda]$ is R-AVD
- $G[V \setminus V_\lambda]$ is R-AVD

1.3 Families of graphs

The following definitions presents some families of graphs and their notations, used in the further sections.

Definition 3

- Let a be a positive integer. P_a denotes the path of order a , C_a the cycle of order a (cp. Figures 1a and 1b).
- A k -pode $T_k(t_1, \dots, t_k)$ is a tree of order $1 + \sum_{i=1}^k t_i$ composed by k paths of order respectively t_1, \dots, t_k , connected to a unique node, called the root of the k -pode (cp. Figure 1c).
- Let a and b be two positive integers. A caterpillar $Cat(a, b)$ is a tree of order $a + b$, composed by three paths of order a , b and 2 , sharing exactly one node, called the root of the caterpillar. $Cat(a, b)$ is isomorphic to $T_3(a - 1, b - 1, 1)$ (cp. Figure 1d).
- A sun with r rays is a graph of order $n \geq 2r$ with r hanging vertices u_1, \dots, u_r whose deletion yields a cycle C_{n-2r} , and each vertex v_i adjacent to u_i is of degree three. If the sequence of vertices v_i is situated on the cycle C_{n-2r} in such a way that there are exactly $a_i \geq 0$ vertices, each of degree two, between v_i and v_{i+1} , $i = 1, \dots, r$ (the indices taken modulo r), then this sun is denoted by $Sun(a_1, \dots, a_r)$, and is unique up to isomorphism (cp. Figure 1e).
Note that the order of $Sun(a_1, \dots, a_r)$ equals $n = 2r + a_1 + \dots + a_r$.

1.4 On-line Arbitrarily Vertex-Decomposable Graphs

The notion of on-line arbitrarily vertex decomposable graph has been introduced by Horňák and al. in [HTW07].

Let $G = (V, E)$ be a graph. Imagine now the following decomposition procedure consisting of k stages, where k is a random variable attaining values from $[1, n]$. In the i^{th} stage, where $i \in [1, k]$, a positive integer τ_i arrives and we have to choose a subset V_i of V of order τ_i that is disjoint from all subsets of V chosen in previous stages (without a possibility of changing the choice in the future). More precisely, for every partial sequence (τ_1, \dots, τ_i) whose sum is less than n , there is a sequence (V_1, \dots, V_i) of disjoint subsets of V such that for $1 \leq j \leq i$, $|V_j| = \tau_j$, with the following property: for all sequences $(\tau'_1, \dots, \tau'_k)$ with $k \geq i$ and summing to n , such that $\tau'_r = \tau_r$ for $1 \leq r \leq i$, there is a decomposition of V into disjoint subsets V'_1, \dots, V'_k with $|V'_j| = \tau'_j$ and $G[V'_j]$ connected, for all j , and $V'_j = V_j$ for $1 \leq j \leq i$.

Definition 4 [HTW07] If the decomposition procedure can be accomplished for any (random) sequence of positive integers (τ_1, \dots, τ_k) adding up to n , the graph G is said to be On-Line AVD, (in short OL-AVD).

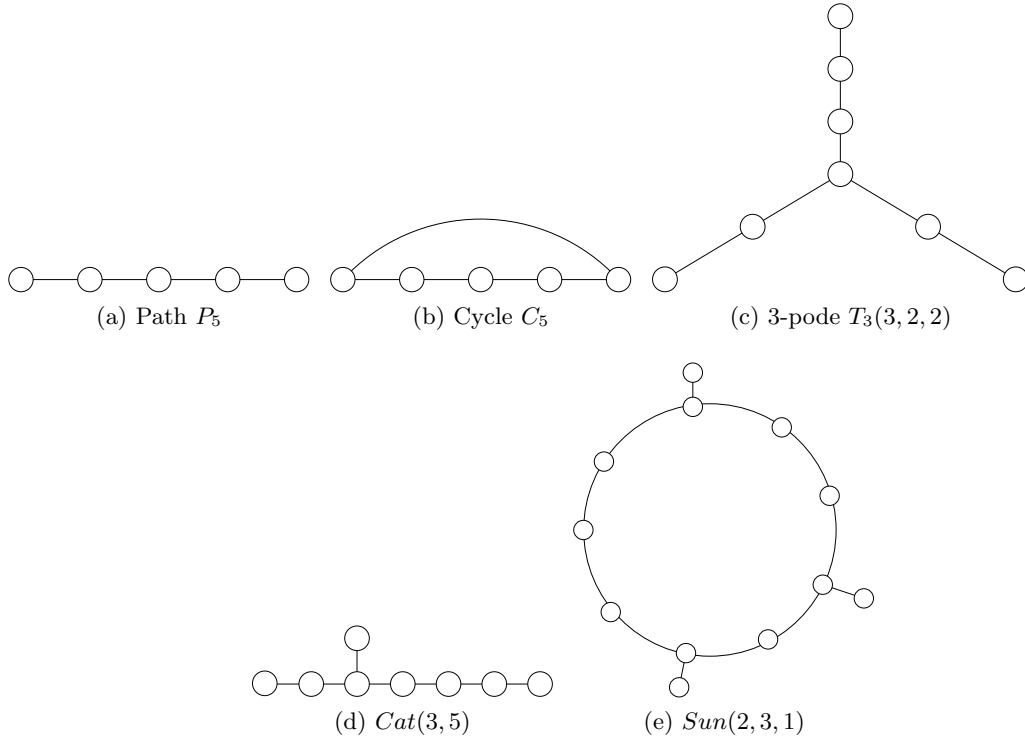


Figure 1: Examples of Graphs

Lemma 5 [HTW07] *A graph $G = (V, E)$ of order n is OL-AVD iff for each integer $1 \leq \lambda \leq n - 1$, it exists a subset V_λ of V such that*

- $|V_\lambda| = \lambda$
- $G[V_\lambda]$ is connected
- $G[V \setminus V_\lambda]$ is OL-AVD

Remark 6 *A straightforward consequence of Lemma 5 and Remark 2 is that every R-AVD graph is OL-AVD.*

The opposite is not true. For example, the caterpillar $Cat(8, 11)$ is OL-AVD [HTW07], but not R-AVD (cp. Section 2).

The next result gives a complete characterization of OL-AVD suns.

Theorem 7 [KPWZ08b]

A sun with one ray is always OL-AVD.

A sun with two rays $Sun(a, b)$ is OL-AVD iff a and b take values given in Table 1a.

A sun with three rays $Sun(a, b, c)$ is OL-AVD iff a , b and c take values given in Table 1b.

A sun with four rays is OL-AVD iff it is isomorphic to $Sun(0, 0, 1, d)$, where $d \equiv 2, 4 \pmod{6}$.

A sun with five or more rays is never OL-AVD.

2 Recursively AVD suns

Theorem 8

A sun with one ray is always R-AVD.

a	b
0	arbitrary
1, 3	$\equiv 0 \pmod{2}$
2	$\not\equiv 3 \pmod{6}, 3, 9, 21$
4	$\equiv 2, 4 \pmod{6}, [4, 19] \setminus \{15\}$
5	$\equiv 2, 4 \pmod{6}, 6, 18$
6	6, 7, 8, 10, 11, 12, 14, 16
7	8, 10, 12, 14, 16
8	8, 9, 10, 11, 12
9	10, 12

a	b	c
0	0	$\equiv 1, 2 \pmod{3}$
	1	$\equiv 0 \pmod{2}$
	2	$\equiv 2, 4 \pmod{6}, 3, 6, 7, 11, 18, 19$
	3	$\equiv 2, 4 \pmod{6}$
	4	4, 5, 6, 8, 10, 11, 12, 14, 16
	5	6, 8, 16
	6, 7	8, 10
	8	8, 9
1	2	$\equiv 2, 4 \pmod{6}, 6, 18$
2	3	4, 8, 16

(a) Values a, b ($b \geq a$), such that $Sun(a, b)$ is OL-AVD

(b) Values a, b, c ($c \geq b \geq a$), such that $Sun(a, b, c)$ is OL-AVD

Table 1: Values for OL-AVD Suns

A sun with two rays $Sun(a, b)$ is R-AVD if and only if a and b take values given in Table 2a. A sun with three rays $Sun(a, b, c)$ is R-AVD if and only if a, b and c take values given in Table 2b. A sun with four rays is R-AVD if and only if it is isomorphic to $Sun(0, 0, 1, 2)$ or to $Sun(0, 0, 1, 4)$. A sun with five or more rays is never R-AVD.

a	b
0	arbitrary
1	$\equiv 0 \pmod{2}$
2	$\not\equiv 0 \pmod{3}, 3, 6, 9, 12, 18, 21, 24, 36$
3	$\equiv 0 \pmod{2}$
4	$4 \leq b \leq 19$ except for $b = 15$, $\equiv 2, 4 \pmod{6}$ with $20 \leq b \leq 46$
5	$\equiv 2, 4 \pmod{6}$ with $8 \leq b \leq 32, 6, 18$
6	6, 7, 8, 10, 11, 12, 14, 16

a	b	c
0	0	$\equiv 1, 2 \pmod{3}$
	1	$\equiv 0 \pmod{2}$
	2	2, 3, 4, 6, 7, 8, 10, 11, 14, 16, 18, 19
	3	4, 8, 10
	4	4, 5, 6, 8, 10, 11, 12, 14, 16
5	6	
1	2	2, 4, 6, 8, 10, 14, 16, 18
2	3	4

(a) Values a, b ($b \geq a$), such that $Sun(a, b)$ is R-AVD

(b) Values a, b, c ($c \geq b \geq a$), such that $Sun(a, b, c)$ is R-AVD

Table 2: Values for R-AVD Suns

Proof.

Since every R-AVD graph is also OL-AVD, so, we shall use the complete characterization of OL-AVD suns given in Theorem 7, and Remark 2.

The labelling used in the proof follows that one from Figure 2.

Sun with one ray A sun with one ray is traceable. Thus, it is R-AVD.

Sun with two rays Without loss of generality, we consider $Sun(a, b)$ with $b \geq a$.

- $Sun(0, b)$ is traceable and then is R-AVD.

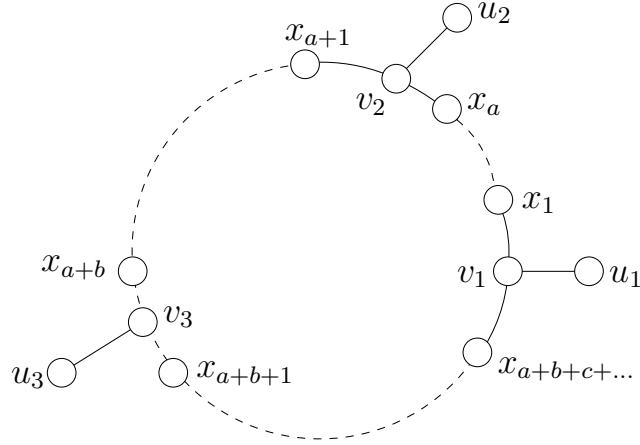


Figure 2: $Sun(a, b, \dots)$

- $Sun(1, b)$ contains $Cat(2, b+3)$ as partial graph. Thus, $Sun(1, b)$ with $b \equiv 0 \pmod{2}$ is R-AVD.
- $Sun(2, b)$ is OL-AVD only for $b \not\equiv 3 \pmod{6}$ or $b = 3, 9, 21$.
 - $Sun(2, b)$ contains $Cat(3, b+3)$ as spanning tree and thus is R-AVD for $b \not\equiv 0 \pmod{3}$.
 - If $b = 6k$ with $k = 5$ or $k \geq 7$, it is not possible to find a partition into two R-AVD subgraphs of size 18 and $n - 18$.
 - If $b \in \{3, 6, 9, 12, 18, 21, 24, 36\}$, then $Sun(2, b)$ is R-AVD and the values of $G[V_\lambda]$ and $G[V \setminus V_\lambda]$ are given in Table 3.
- $Sun(3, b)$ contains $Cat(4, b+1)$ as a spanning tree. Thus, it is R-AVD for $b \equiv 0 \pmod{2}$.
- $Sun(4, b)$ is OL-AVD only for $b \equiv 2, 4 \pmod{6}$ or $b \in \{4, \dots, 19\} \setminus \{15\}$.
 - $Sun(4, b)$ contains $Cat(5, b+3)$ as a spanning tree. Thus, it is R-AVD for $b \in \{4, 6, 8, 11, 16\}$.
 - Similarly, $Sun(4, b)$ contains $Cat(7, b+1)$ as a spanning tree. Thus, it is R-AVD for $b \in \{7, 10, 12, 14\}$.
 - Let us consider the case where $b \equiv 2, 4 \pmod{6}$.
 - * If $b \geq 50$, then $n = b + 8 \geq 58$. Then, we have to consider the case $\lambda = 30$ with $n - \lambda \geq 28$. Because there is no caterpillar with order 30, $G[V_\lambda]$ must be a path and $G[V \setminus V_\lambda]$ a caterpillar $Cat(5, x)$ or $Cat(7, x)$. But such a caterpillar has a maximum order 24. Thus, if $b \geq 50$, $Sun(4, b)$ cannot be R-AVD.
 - * For $b \equiv 2, 4 \pmod{6}$, $20 \leq b \leq 46$, all the $Sun(4, b)$ are R-AVD and the values of $G[V_\lambda]$ and $G[V \setminus V_\lambda]$ are given in Table 4.
 - For the last possible values of b , that is $b \in \{5, 9, 13, 17, 18, 19\}$, $Sun(4, b)$ is R-AVD and the values of $G[V_\lambda]$ and $G[V \setminus V_\lambda]$ are given in Table 4.
- $Sun(5, b)$ is OL-AVD only for $b \equiv 2, 4 \pmod{6}$ or $b \in \{6, 18\}$.
 - Consider the case $b \equiv 2, 4 \pmod{6}$. For $\lambda = 18$, the only possibility is that $G[V_{18}] = P_{18}$. But in that case, $G[V \setminus V_{18}]$ must be a caterpillar $Cat(6, x)$ or $Cat(8, x)$, which is impossible for $n - 18 \geq 14$, that is $n \geq 32$ and $b \geq 23$. Thus $Sun(5, b)$ may be R-AVD only for $b \equiv 2, 4 \pmod{6}$ with $8 \leq b \leq 22$ or $b \in \{6, 18\}$.
 - For all the remaining values of b , that is $b \in \{6, 8, 10, 14, 16, 18, 20, 22\}$, $Sun(5, b)$ is R-AVD and the values of $G[V_\lambda]$ and $G[V \setminus V_\lambda]$ are given in Table 5.
- $Sun(6, b)$ is OL-AVD only for $b \in \{6, 7, 8, 10, 11, 12, 14, 16\}$.

- Observe that $\text{Sun}(6, b)$ contains, as a spanning tree, the caterpillar $\text{Cat}(7, b + 3)$. Thus, $\text{Sun}(a, b)$ is R-AVD for $b \in \{6, 8, 10, 12\}$.
- For all the remaining values of b , that is $b \in \{7, 11, 14, 16\}$, $\text{Sun}(6, b)$ is R-AVD and the values of $G[V_\lambda]$ and $G[V \setminus V_\lambda]$ are given in Table 6.
- $\text{Sun}(7, b)$ is OL-AVD only for $b \in \{8, 10, 12, 14, 16\}$. For all of these values of b , it is not possible to find an edge $\{w_1, w_2\}$ such that $G[V \setminus \{w_1, w_2\}]$ is R-AVD.
- $\text{Sun}(8, b)$ is OL-AVD only for $b \in \{8, 9, 10, 11, 12\}$.
 - For $b \in \{8, 10, 11, 12\}$, it is not possible to find a set of size 3 V_3 such that both $G[V_3]$ and $G[V \setminus V_3]$ are R-AVD.
 - For $b = 9$, it is not possible to find an edge $\{w_1, w_2\}$ such that $G[V \setminus \{w_1, w_2\}]$ is R-AVD.
- $\text{Sun}(9, b)$ is OL-AVD only for $b \in \{10, 12\}$. For these two values of b , it is not possible to find an edge $\{w_1, w_2\}$ such that $G[V \setminus \{w_1, w_2\}]$ is R-AVD.

b	λ	V_λ	$G[V_\lambda]$	$G[V \setminus V_\lambda]$
3, 6, 9, 12, 18, 21, 24, 36	1	$\{u_1\}$	P_1	Sun with one ray
	2	$\{x_1, x_2\}$	P_2	P_{b+4}
3	3	$\{x_3, x_4, x_5\}$	P_3	P_6
6, 12, 18, 24, 36		$\{x_2, v_2, u_2\}$	P_3	$\text{Cat}(2, b + 1)$
9, 21		$\{x_{a+b-2}, x_{a+b-1}, x_{a+b}\}$	P_3	$\text{Cat}(5, b - 2)$
3, 6, 9, 12, 18, 21, 24, 36	4	$\{u_1, 1_2, x_1, x_2\}$	P_4	P_{b+2}
6, 9, 12, 18, 21, 24, 36	5	$\{x_1, x_2, v_2, u_2, x_3\}$	$\text{Cat}(2, 3)$	P_{b+1}
	6	$\{u_1, v_1, x_1, x_2, v_2, u_2\}$	P_6	P_b
9, 12, 18, 21, 24, 36	7	$\{u_1, v_1, x_1, x_2, v_2, u_2, x_3\}$	$\text{Cat}(2, 5)$	P_{b-1}
12, 18, 21, 24, 36	8	$\{u_1, v_1, x_1, x_2, v_2, u_2, x_3, x_4\}$	$\text{Cat}(3, 5)$	P_{b-2}
	9	$\{u_1, v_1, x_1, x_2, v_2, u_2, x_3, x_4, x_5\}$	$\text{Cat}(4, 5)$	P_{b-3}
18, 21, 24, 36	10	$\{x_1, x_2, v_2, u_2, x_3, \dots, x_8\}$	$\text{Cat}(3, 7)$	P_{b-4}
	11	$\{x_1, x_2, v_2, u_2, x_3, \dots, x_9\}$	$\text{Cat}(3, 8)$	P_{b-5}
	12	$\{u_1, v_1, x_1, x_2, v_2, u_2, x_3, \dots, x_8\}$	$\text{Cat}(5, 7)$	P_{b-6}
21, 24, 36	13	$\{x_1, x_2, v_2, u_2, x_3, \dots, x_{11}\}$	$\text{Cat}(3, 10)$	P_{b-7}
24, 36	14	$\{x_1, x_2, v_2, u_2, x_3, \dots, x_{12}\}$	$\text{Cat}(3, 11)$	P_{b-8}
	15	$\{x_2, v_2, u_2, x_3, \dots, x_{14}\}$	$\text{Cat}(2, 13)$	$\text{Cat}(2, b - 11)$
36	16	$\{x_1, x_2, v_2, u_2, x_3, \dots, x_{14}\}$	$\text{Cat}(3, 13)$	P_{26}
	17	$\{x_1, x_2, v_2, u_2, x_3, \dots, x_{15}\}$	$\text{Cat}(3, 14)$	P_{25}
	18	$\{x_{21}, \dots, x_{38}\}$	P_{18}	$\text{Cat}(5, 19)$
	19	$\{x_1, x_2, v_2, u_2, x_3, \dots, x_{17}\}$	$\text{Cat}(3, 16)$	P_{23}
	20	$\{x_1, x_2, v_2, u_2, x_3, \dots, x_{18}\}$	$\text{Cat}(3, 17)$	P_{22}
	21	$\{x_2, v_2, u_2, x_3, \dots, x_{20}\}$	$\text{Cat}(2, 19)$	$\text{Cat}(2, 19)$

Table 3: Values of $G[V_\lambda]$ and $G[V \setminus V_\lambda]$ for some $\text{Sun}(2, b)$

Sun with three rays Without loss of generality, we consider $\text{Sun}(a, b, c)$ with $c \geq b \geq a$.

- $\text{Sun}(0, 0, c)$ is OL-AVD only for $c \equiv 1, 2 \pmod{3}$. Because $\text{Sun}(0, 0, c)$ contains $\text{Cat}(3, c + 3)$ as a spanning tree, thus it is also R-AVD for $c \equiv 1, 2 \pmod{3}$.

b	λ	V_λ	$G[V_\lambda]$	$G[V \setminus V_\lambda]$
5, 9, 13, 17, 18, 19 $b \equiv 2, 4 \pmod{6}, 20 \leq b \leq 46$	1	$\{u_1\}$	P_1	Sun with one ray
5, 13, 17, 19 $b \equiv 2, 4 \pmod{6}, 20 \leq b \leq 46$	2	$\{x_1, x_2\}$	P_2	$Cat(3, b+3)$
9		$\{x_5, x_6\}$	P_2	$Cat(7, 8)$
18		$\{u_1, v_1\}$	P_2	$Cat(5, 19)$
5, 13, 17	3	$\{x_5, x_6, x_7\}$	P_3	$Cat(7, b-2)$
9, 19		$\{u_2, v_2, x_5\}$	P_3	$Cat(5, b)$
18 $b \equiv 2, 4 \pmod{6}, 20 \leq b \leq 46$		$\{x_1, x_2, x_3\}$	P_3	$Cat(2, b+3)$
5, 9, 13, 17, 18, 19 $b \equiv 2, 4 \pmod{6}, 20 \leq b \leq 46$	4	$\{x_1, \dots, x_4\}$	P_4	P_{b+4}
5, 13, 17, 19	5	$\{x_3, x_4, v_2, u_2, x_5\}$	$Cat(2, 3)$	$Cat(3, b)$
9		$\{x_5, \dots, x_9\}$	P_5	$Cat(5, 7)$
18 $b \equiv 2, 4 \pmod{6}, 20 \leq b \leq 46$		$\{x_4, v_2, u_2, x_5, x_6\}$	$Cat(2, 3)$	$Cat(4, b-1)$
5, 9, 13, 17, 18, 19 $b \equiv 2, 4 \pmod{6}, 20 \leq b \leq 46$	6	$\{u_1, v_1, x_1, \dots, x_4\}$	P_6	P_{b+2}
9, 13, 19	7	$\{x_3, x_4, v_2, u_2, x_5, x_6, x_7\}$	$Cat(3, 4)$	$Cat(3, b-2)$
17		$\{x_{15}, \dots, x_{21}\}$	P_7	$Cat(7, 11)$
18 $b \equiv 2, 4 \pmod{6}, 20 \leq b \leq 46$		$\{x_4, v_2, u_2, x_5, \dots, x_8\}$	$Cat(2, 5)$	$Cat(4, b-3)$
9, 13, 17, 18, 19 $b \equiv 2, 4 \pmod{6}, 20 \leq b \leq 46$	8	$\{u_1, v_1, x_1, \dots, x_4, v_2, u_2\}$	P_8	P_b
13, 17, 18, 19	9	$\{x_1, \dots, x_4, v_2, u_2, x_5, x_6, x_7\}$	$Cat(4, 5)$	P_{b-1}
$b \equiv 2, 4 \pmod{6}, 20 \leq b \leq 46$	10	$\{u_1, v_1, x_1, \dots, x_4, v_2, u_2, x_5, x_6\}$	$Cat(3, 7)$	P_{b-2}
17, 18, 19	11	$\{x_1, \dots, x_4, v_2, u_2, x_5, \dots, x_9\}$	$Cat(5, 6)$	P_{b-3}
$b \equiv 2, 4 \pmod{6}, 20 \leq b \leq 46$	12	$\{x_1, \dots, x_4, v_2, u_2, x_5, \dots, x_{10}\}$	$Cat(5, 7)$	P_{b-4}
18, 19	13	$\{u_1, v_1, x_1, \dots, x_4, v_2, u_2, x_5, \dots, x_9\}$	$Cat(6, 7)$	P_{b-5}
$b \equiv 2, 4 \pmod{6}, 20 \leq b \leq 46$	14	$\{x_1, \dots, x_4, v_2, u_2, x_5, \dots, x_{12}\}$	$Cat(5, 9)$	P_{b-6}
$b \equiv 2, 4 \pmod{6}, 22 \leq b \leq 46$	15	$\{x_4, v_2, u_2, x_5, \dots, x_{16}\}$	$Cat(2, 13)$	$Cat(4, b-11)$
	16	$\{x_1, \dots, x_4, v_2, u_2, x_5, \dots, x_{14}\}$	$Cat(5, 11)$	P_{b-8}
26, 28, 32, 34, 38, 40, 44, 46	17	$\{x_4, v_2, u_2, x_5, \dots, x_{18}\}$	$Cat(2, 15)$	$Cat(4, b-13)$
28, 32, 34, 38, 40, 44, 46	18	$\{u_1, v_1, x_1, \dots, x_4, v_2, u_2, x_5, \dots, x_{14}\}$	$Cat(7, 11)$	P_{b-10}
	19	$\{x_4, v_2, u_2, x_5, \dots, x_{20}\}$	$Cat(2, 17)$	$Cat(4, b-15)$
32, 34, 38, 40, 44, 46	20	$\{u_1, v_1, x_1, \dots, x_4, v_2, u_2, x_5, \dots, x_{16}\}$	$Cat(7, 13)$	P_{b-12}
34, 38, 40, 44, 46	21	$\{x_4, v_2, u_2, x_5, \dots, x_{22}\}$	$Cat(2, 19)$	$Cat(4, b-17)$
	22	$\{u_1, v_1, x_1, \dots, x_4, v_2, u_2, x_5, \dots, x_{18}\}$	$Cat(7, 15)$	P_{b-14}
38, 40, 44, 46	23	$\{x_4, v_2, u_2, x_5, \dots, x_{24}\}$	$Cat(2, 21)$	$Cat(4, b-19)$
40, 44, 46	24	$\{x_1, \dots, x_4, v_2, u_2, x_5, \dots, x_{22}\}$	$Cat(5, 19)$	P_{b-16}
	25	$\{x_4, v_2, u_2, x_5, \dots, x_{26}\}$	$Cat(2, 23)$	$Cat(4, b-21)$
44, 46	26	$\{x_3, x_4, v_2, u_2, x_5, \dots, x_{26}\}$	$Cat(3, 23)$	$Cat(3, b-21)$
46	27	$\{x_4, v_2, u_2, x_5, \dots, x_{28}\}$	$Cat(2, 25)$	$Cat(4, 23)$

Table 4: Values of $G[V_\lambda]$ and $G[V \setminus V_\lambda]$ for some Sun $(4, b)$

b	λ	V_λ	$G[V_\lambda]$	$G[V \setminus V_\lambda]$
6, 8, 10, 14, 16, 18, 20, 22	1	$\{u_1\}$	P_1	Sun with one ray
	2	$\{x_1, x_2\}$	P_2	$Cat(4, b+7)$
6, 18	3	$\{u_1, v_1, x_1\}$	P_3	$Cat(5, b+1)$
8, 10, 14, 16, 20, 22		$\{x_1, x_2, x_3\}$	P_3	$Cat(3, b+3)$
6, 8, 10, 14, 16, 18, 20, 22	4	$\{x_1, x_2, x_3, x_4\}$	P_4	$Cat(2, b+5)$
	5	$\{x_1 \dots, x_5\}$	P_5	P_{b+4}
	6	$\{x_2 \dots, x_5, v_2, u_2\}$	P_6	$Cat(2, b+1)$
	7	$\{u_1, v_1, x_1 \dots, x_5\}$	P_7	P_{b+2}
8, 10, 14, 16, 18, 20, 22	8	$\{x_2 \dots, x_5, v_2, u_2, x_6, x_7\}$	$Cat(3, 5)$	$Cat(2, b-1)$
10, 14, 16, 18, 20, 22	9	$\{u_1, v_1, x_1 \dots, x_5, v_2, u_2\}$	P_9	P_b
14, 16, 18, 20, 22	10	$\{x_4, x_5, v_2, u_2, x_6, \dots, x_{11}\}$	$Cat(3, 7)$	$Cat(4, b-5)$
	11	$\{u_1, v_1, x_1 \dots, x_5, v_2, u_2, x_6, x_7\}$	$Cat(3, 8)$	P_{b-2}
16, 18, 20, 22	12	$\{x_2, \dots, x_5, v_2, u_2, x_6, \dots, x_{11}\}$	$Cat(5, 7)$	$Cat(2, b-5)$
18, 20, 22	13	$\{x_1, \dots, x_5, v_2, u_2, x_6, \dots, x_{11}\}$	$Cat(6, 7)$	P_{b-4}
20, 22	14	$\{x_2, \dots, x_5, v_2, u_2, x_6, \dots, x_{13}\}$	$Cat(5, 9)$	$Cat(2, b-7)$
22	15	$\{u_1, v_1, x_1 \dots, x_5, v_2, u_2, x_6, \dots, x_{11}\}$	$Cat(7, 8)$	P_{16}

Table 5: Values of $G[V_\lambda]$ and $G[V \setminus V_\lambda]$ for Sun $(5, b)$

b	λ	V_λ	$G[V_\lambda]$	$G[V \setminus V_\lambda]$
7, 11, 14, 16	1	$\{u_1\}$	P_1	Sun with one ray
7, 14	2	$\{u_1, v_1\}$	P_2	$Cat(7, b+1)$
11, 16		$\{x_1, x_2\}$	P_2	$Cat(5, b+3)$
7	3	$\{x_7, x_8, x_9\}$	P_3	$Cat(5, 9)$
11		$\{v_2, u_2, x_7\}$	P_3	$Cat(7, b)$
14, 16		$\{x_1, x_2, x_3\}$	P_3	$Cat(4, b+3)$
7, 11, 14, 16	4	$\{x_1, \dots, x_4\}$	P_4	$Cat(3, b+3)$
7, 11	5	$\{x_5, x_6, v_2, u_2, x_7\}$	$Cat(2, 3)$	$Cat(5, b)$
14, 16		$\{x_1, \dots, x_5\}$	P_5	$Cat(2, b+3)$
7, 11, 14, 16	6	$\{x_1, \dots, x_6\}$	P_6	P_{b+4}
7, 11	7	$\{x_3, \dots, x_6, v_2, u_2, x_7\}$	$Cat(2, 5)$	$Cat(3, b)$
14, 16		$\{x_2, \dots, x_6, v_2, u_2\}$	P_7	$Cat(2, b+1)$
7, 11, 14, 16	8	$\{x_1, \dots, x_6, v_2, u_2\}$	P_8	P_{b+2}
11, 14, 16	9	$\{x_1, \dots, x_6, v_2, u_2, x_7, \dots, x_{\lambda-2}\}$	$Cat(\lambda-7, 7)$	$P_{b+10-\lambda}$
	10			
14, 16	11			
	12			
16	13			

Table 6: Values of $G[V_\lambda]$ and $G[V \setminus V_\lambda]$ for some Sun $(6, b)$

- $\text{Sun}(0,1,c)$ is OL-AVD only for $c \equiv 0 \pmod{2}$. Because $\text{Sun}(0,1,c)$ contains $\text{Cat}(4, c + 3)$ as a spanning tree, thus it is also R-AVD for $c \equiv 0 \pmod{2}$.
- $\text{Sun}(0,2,c)$ is OL-AVD only for $c \equiv 2, 4 \pmod{6}$ or $c \in \{3, 6, 7, 11, 18, 19\}$. Because $\text{Sun}(0,1,c)$ contains $\text{Cat}(4, c + 3)$ as a spanning tree, thus it is also R-AVD for $c \equiv 0 \pmod{2}$.
 - $\text{Sun}(0,2,c)$ contains $\text{Cat}(5, c + 3)$ as a spanning tree, thus it is R-AVD for $c \in \{3, 6, 11\}$.
 - For $c \in \{7, 18, 19\}$, $\text{Sun}(0, 2, c)$ is R-AVD and the values of $G[V_\lambda]$ and $G[V \setminus V_\lambda]$ are given in Table ??.

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TO COMPLETE

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